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Collection of Schedule Quality Metrics and Application to Projects of the Office of Facilities Planning and Construction (OFPC)

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Collection of Schedule Quality Metrics and Application to Projects of the Office of Facilities Planning and Construction (OFPC)

by

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Abstract

Collection of Schedule Quality Metrics and Application to Projects of the Office of Facilities Planning and Construction (OFPC)

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Construction projects are costly, time-consuming, and complex so that a sound plan is essential to execute them successfully. Schedules play a key role as a roadmap that shows how and when a project delivers its products defined in the project scope (PMI 2007). In an effort to facilitate scheduling process, diverse scheduling software programs have been developed and used. Nevertheless, substantial knowledge, experience, and efforts are still required to create a quality schedule. As such, many government agencies and professional organizations have recommended a variety of important concepts, metrics, and thresholds to help contractors develop decent baseline schedules and help owners check their quality.

The first objective of this research is to compile, select, and organize the recommended schedule quality metrics and thresholds as tools for checking and improving the quality of baseline schedules. The second objective is to apply these metrics to baseline schedules used for the Office of Facilities Planning and Construction (OFPC) projects on the campus of the University of Texas at Austin and analyze the evaluation findings to provide recommendations for future projects.

Through an extensive literature review, 11 publications from 10 government agencies and professional organizations have been studied and 49 baseline schedule quality metrics and thresholds are compiled and selected. These metrics are divided into 9 groups; General, Milestone, Duration, Calendar, Logic, Constraint, Float, Lag, and Lead. Followed was the evaluation of the baseline schedules used for OFPC projects by these metrics and thresholds to provide recommendations for future projects.

The evaluation results show that every project passed 27 metrics while at least one project failed to pass 22 metrics. The majority of projects, 7 out of 13, missed 11 tests. These tests are associated with maximum duration limit (30 work days), high total float (44 work days), maximum total float (total float on the longest path + 45 work days), ratio of detail tasks to milestones, percentage of tasks on the critical path, number of lags, unique task names, open ends, extreme total float (120 work days), relationship type, and milestones missing a predecessor or successor. With regards to recommendations for future OFPC projects, emphasis is placed on the metrics that the majority of projects failed to pass as well as that are regarded as crucial for reviewing schedules.

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Chapter 1: Introduction

1.1 Motivation

Construction projects are costly, time-consuming, and complex so that a sound plan is essential to execute them successfully. Schedules play a key role as a roadmap that shows how and when a project delivers its products defined in the project scope (PMI 2007). As such, diverse scheduling software programs, for example, MS Project and Primavera, are in use to facilitate the development of schedules. Nevertheless, developing a quality schedule requires a great amount of knowledge, experience, and efforts. In fact, it is common to see rejections of many schedules submitted by contractors. As such, according to Project Management Institute (PMI), standards to develop sound schedules as well as methods to assess the adequacy of schedules are requested by project management community (PMI 2007). This is why many government agencies and professional organizations have recommended a variety of important concepts, metrics, and thresholds to help contractors develop decent baseline schedules and help owners check their quality. For instance, the Office of Facilities Planning and Construction (OFPC) explicitly states important information that needs to be included or considered in baseline schedules through Project Planning and Scheduling specifications. In this sense, standards for scheduling and evaluating tools based on metrics and thresholds will make a profound contribution to developing quality schedules.

1.2 Objectives

Various organizations have suggested concepts, metrics, and thresholds for scheduling based on their best practices or recommendations. However, their suggestions have not been collected and organized. As a result, the first objective of this research is to compile, select, and organize schedule quality metrics and thresholds as tools for checking and improving the quality of baseline schedules. The second objective is to contribute to reviewing and evaluating baseline schedules for OFPC projects based on the schedule quality evaluation results of their previous projects by the metrics. For these objectives, this research first develops a comprehensive and combined list of metrics and thresholds. After that, it evaluates the baseline schedules used for the OFPC construction projects that were executed on the campus of the University of Texas at Austin by the collected metrics, analyzes the evaluation results, and provides suggestions about what should be checked or can be improved in the future schedules of OFPC projects.

1.3 Research Scope and Limitations

This research focuses on the metrics for creating or evaluating baseline schedules but not for measuring the progress of a project. In other words, metrics related with Earned Value Method, such as CPI, SPI, EAC, CV, SV, etc., are not within the scope of this research. In terms of baseline schedule data, only that of completed OFPC construction projects was collected and used so that suggestions for future projects are mainly targeting OFPC projects.

1.4 ORGANIZATION OF THE THESIS

Chapter 2 (Literature Review) provides key definitions for this research and states the importance and uses of schedules. Chapter 3 (Research Methodology) summarizes the process of this research. The information of OFPC projects will be dealt with in Chapter 4 (OFPC Projects Information). Chapter 5 (Findings) provides detailed information on each metric and analyzes the results of OFPC project evaluation. Chapter 6 (Conclusions) provides the conclusions of this thesis based on Chapter 5 and Chapter 7 (Recommendations) makes suggestions for OFPC's future projects.

Chapter 2: Literature Review

In this literature review chapter, key definitions commonly used in this thesis are provided and the importance of quality schedules for successful projects is explained. Also, crucial uses of baseline schedules in construction projects are described. Following are references for quantitative baseline schedule quality metrics and thresholds that are utilized in this research.

2.1 Key Definitions

The definitions of baseline schedule, metric, threshold, longest path, critical path, level of effort, and hammock task are as follows;

- Baseline Schedule: The first version of the schedule that shows a fixed projection of the project (OFPC 2011), meets the project execution plan (AACEI 2013), and is completed to be approved by management (PMI 2007).

- Metric: A quantifiable, simple, and understandable measure that can be utilized to compare and improve performance (Spillinger 2000).

- Threshold: A minimum or maximum value that serves as a benchmark for comparison or guidance and any breach of which may call for a complete review of the situation or the redesign of a system (BusinessDictionary.com 2015).

- Longest Path: The sequence of interdependent activities that aggregate to determine the minimum duration of a project (OFPC 2011). Longest path is determined by the string of activities, relationships, and lags that push the project to its earliest finish date (AACEI 2014).

- Critical Path: The longest continuous chain of activities which establishes the minimum overall project duration. A delay in completion of any activity on the critical path will extend the completion date of a project. The critical path by definition has zero total float (AACEI 2014). If the longest path has zero or less total float, the longest path becomes the critical path (OFPC 2011). A constraint can cause an activity to have zero total float and to be on the critical path but not on the longest path. In this case, the longest path is preferred since it represents the activities that are determining the schedule finish date (GAO 2012).

- Level of Effort (LOE): LOE activities represent support effort that has no measurable output and cannot be associated with a physical product or defined deliverable. LOE activities are commonly related with management and other oversight that continues until the detailed activities they support have been completed. Their progress is measured based on the passage of time (GAO 2012).

- Hammock Task: Hammock tasks represent a roll-up or summary of schedule information on a group of tasks including duration and dates. Hammock tasks can represent any group of tasks in the schedule regardless of their physical location or parent Work Breakdown Structure (WBS) element (NDIA 2012).

2.2 Importance of Schedule

The key to project success is to develop a sound project plan or schedule and to carry out the project according to the plan (PMI 2007). As a result, a schedule is one of the fundamental deliverables that owners require contractors to submit for approval upon the award of contracts (Moosavi and Moselhi 2014). In addition to showing the sequence of work to deliver products, schedules enable the arrangement of funds on required dates, mobilization and allocation of resources in an efficient way, and early identification of problems so that corrective actions can be taken in a timely manner to achieve project goals as planned (PMI 2007). In other words, a properly developed schedule provides the necessary information to assist project managers in acting promptly for any schedule delays and cost overruns (Li and Carter 2005). Also, schedules are regarded as important documents used to record delays and to analyze time extensions and financial loss claims (PMI 2007).

A quality schedule would be the one that is in line with related contracts, covers the scope of work thoroughly, clearly describes how projects will be performed, and has practical and realistic logics and durations (Moosavi and Moselhi 2014). GAO provided the four characteristics of a quality and reliable schedule. GAO identified that a quality schedule has 4 characteristics; comprehensive, well-constructed, credible, and controlled To begin with, a comprehensive schedule includes all the necessary activities as defined in the project's WBS in order to achieve a project's objectives. This schedule also provides information on labor and resources needed to perform the project and reflects how long each activity will take. A schedule will be considered as well-constructed if its activities are sequenced with the most straightforward logic possible. It is recommended that unusual or complex logic techniques are explained and justified when utilized. A schedule that can be both horizontally and vertically traceable is regarded as a credible schedule. To be more specific, a horizontally traceable schedule represents the order of events required to achieve a project's objectives. In a vertically traceable schedule, activities in different levels map to one another as well as key dates informed to management are aligned with the schedule. Lastly, a schedule is considered as controlled if it is updated on a regular basis using actual progress and logic to forecast realistic start and finish dates of tasks. A controlled schedule enables comparison between a project's plan and actual progress to identify variances and tackle problems in a timely manner (GAO 2012).

2.3 BASELINE SCHEDULE

A baseline schedule represents the original configuration of a program or project plan and implies the consensus of all stakeholders concerning the required sequence of events, resource assignments, and acceptable dates for key deliverables (GAO 2012). Thus, it is developed promptly after the program or project begins. Moreover, it is used to measure progress and identify trends and changes in terms of cost and time. It also makes it possible to identify the impact of any milestones or completion date variances when compared with an updated schedule (AACEI 2013). This is why the baseline schedule is frequently used to justify or deny time extensions and inefficiency losses and, therefore, can have tremendous financial consequences (Zafar and Rasmussen 2001). In addition, the baseline schedule is the foundation for planning cash flows, managing resources, forecasting costs and schedules, and reporting (AACEI 2013). Moreover, baseline schedules provide the legal basis for the administration of construction disputes and claims (Moosavi and Moselhi 2014). For these reasons, it is important to develop a quality baseline schedule and to closely review it when submitted.

Generally speaking, a contract requires a baseline schedule to be submitted 30 days after the Notice to Proceed (NTP) but such policy can be different from agency to agency. As for the review process, it can take at least two weeks for the owner. To have a mutually acceptable baseline schedule between the owner and contractor, it can take more than one month (Zafar and Rasmussen 2001). It can be imagined that baseline schedules are commonly rejected when submitted to the owner. According to the records of a construction consulting firm, it is common to see that 99 percent of the baseline schedules fail to fully comply with contract documents in the first submittal. In the second submittal, roughly 30 to 40 percent of baseline schedules are still rejected. In the third submittal, the percent of rejected schedules goes down to 5 to 10 percent (Li and Carter 2005). Timely approval of the baseline schedule is important for both owners and contractors since contract documents specify that no payment shall be released until the baseline schedule is approved by the owner, which results in a negative impact on a project's performance (OFPC 2011; Li and Carter 2005).

Zafar and Rasmussen summarized the main causes of rejection of a baseline schedule as follows (Zafar and Rasmussen 2001);

- Unbuildable logic;
- Optimistic logic;
- Flow of work not per contract documents;
- Inappropriate float suppression technique used;
- Problems with the schedule mechanic;
- Too much, or too little, detail;
- Schedule does not meet intermediate milestone requirements, and etc.
- An important portion of work is not shown on the schedule;
- Flow of critical path is not logical;

To avoid these causes, it would be wise for contractors to thoroughly review contract requirements, standards, and special provisions and evaluate their schedule quality prior to submission. For owners, having a checklist for evaluating submitted baseline schedules will facilitate the review process and, ultimately, their construction projects.

2.4 Improving the Quality of Baseline Schedules

There have been many efforts to develop structured methods or guidelines to assist owners in performing the assessment and evaluation of schedules submitted by contractors. In an effort to provide or improve the scheduling practices used, the Defense Contract Management Agency (DCMA) developed and released 14-Point Schedule Assessment Checks as a framework for schedule quality control. This 14-Point Schedule Assessment is used for thorough and objective analysis of schedules. It is worth noting that the 14-Point Schedule Assessment is not intended to be used as a standard but only as a guideline (Winter 2011). This review protocol performs tests regarding logics, leads, lags, relationship types, constraints, float, duration, resources, and critical path.

Another organization that has been contributing to schedule assessment practices is the United States Government Accountability Office (GAO). As a government agency striving to use public funds effectively and achieve its goals, it has been seeking methods to develop well-planned, realistic, and achievable schedules. With the belief that a program's success depends on the quality of its schedule, this agency conceived 10 best practices associated with developing and maintaining a reliable and high-quality schedule. The 10 best practices are related with activities, lags, leads, resources, durations, float, and traceability, which are relatively overlapped with the DCMA 14-Point Assessment.

In addition, National Defense Industrial Association (NDIA) developed Planning and Scheduling Excellence Guide (PASEG) to provide the program management team with practical approaches for developing, utilizing, and maintaining schedules. Moreover, this guide gives tips for scheduling techniques that can be applied to any scheduling software (NDIA 2012).

Moosavi and Moselhi (2012) conducted research on schedule assessment and evaluation to suggest a structured methodology for assisting owners in evaluating schedules. This research pointed out important criteria that each schedule should satisfy. Their criteria of a quality schedule are known as contractual compliance, adequate scope of a schedule and process of schedule development, and schedule components. Also, in this research, the developed evaluation methodology was implemented in automated computer application. The purpose of this application was to perform the schedule assessment of large projects with a number of activities in a convenient and rapid manner. Moosavi and Moselhi (2012) added a comment that the developed application can be helpful to contactors since it will play a role as a guideline and recommended practice in scheduling.

When it comes to OFPC, it specifies contract requirements regarding baseline schedules through its Project Planning and Scheduling specifications for quality schedules. Also, OFPC uses a construction schedule review checklist to assess and review a schedule submitted by a contractor. For instance, this evaluation list checks whether proper software is used for the schedule, whether Work Breakdown Structure (WBS) is adequately assigned and aligned with construction documents, and whether minimum total float is provided. In addition, it checks if the schedule has only one activity missing a predecessor (typically, Notice to Proceed), and only one activity missing a successor (typically, Final Completion or Operation Occupancy) and if tasks have excessive float.

2.5 References for Baseline Schedule Metrics

A number of government agencies and professional organizations have been contributing to developing guidelines and/or standards for scheduling. They include Department of Defense (DOD), Defense Contract Management Agency (DCMA), National Defense Industrial Association (NDIA), Project Management Institute (PMI), the Office of Facilities Planning and Construction (OFPC), United States Government Accountability Office (GAO), National Aeronautics and Space Administration (NASA), The Defense Acquisition University (DAU), Naval Air (NAVAIR), and Center for Earned Value Management (CEVM). These organizations have developed their own guidelines or publications in an effort to develop quality schedules as well as to evaluate the adequacy of schedules. A list of these organizations' publications or guidelines for scheduling is provided below. Project Planning and Scheduling specifications from OFPC are rather distinct from other publications since they are stipulated requirements that a contractor should satisfy when submitting a baseline schedule for approval.

Organization	Publication/Guideline Title	Abbreviation
The Department of Defense (DOD)	Over Target Baseline and Over Target Schedule Guide, November 2012	DOD_2012
The Department of Defense (DOD)	Integrated Master Plan and Integrated Master Schedule Preparation and Use Guide, October 2005	DOD_2005
Defense Contract Management Agency (DCMA)	Earned Value Management System (EVMS) Program Analysis Pamphlet (PAP), July 2012	DCMA_2012
National Defense Industrial Association (NDIA)	Planning and Scheduling Excellence Guide, June 2012	NDIA_2012
Project Management Institute (PMI)	Practice Standard for Scheduling, 2007	PMI_2007
The University of Texas System Office of Facilities Planning and Construction (UT OFPC)	Project Planning and Scheduling, Section 01 32 00, Issuance: September 2007, Revision: 3/1/2011 Revision	OFPC_2011
The United States Government Accountability Office (GAO)	Schedule Assessment Guide, May 2012	GAO_2012
National Aeronautics and Space Administration (NASA)	NASA Schedule Management Handbook, NASA/SP-2010-3403, January 2010	NASA_2010
The Defense Acquisition University (DAU)	Better Schedule Performance Assessments Derived From Integrated Master Plan-Referenced Schedule Metrics, October 2011	DAU_2011
Naval Air (NAVAIR)	Integrated Master Schedule (IMS) Guidebook, Version 1.0, February 2010	NAV_2010
Center for Earned Value Management (CEVM)	Analysis Toolkit, August 2008	CEVM_2008

Table 1. List of References for Quantitative Schedule Quality Metrics and Thresholds

It is identified that focusing areas of the government agencies and professional organizations for the development and evaluation of schedules are mostly overlapped but not always. For instance, DCMA suggested diverse metrics and thresholds related to, but not limited to, lag, lead, constraint, and float. In the case of PMI, it mainly focused on calendar, duration, and logic, not to mention constraint, float, lag, and, lead, to develop a high quality and reliable schedule. It is found out that GAO and NDIA provided a wide array of recommendations or best practices in most categories. With regards to OFPC, its requirements are related with the IDs and names of projects and tasks, responsibilities codes, float, maximum duration limit, logics, and, hard constraints.

2.6 Issue Identification

As stated above, many professional organizations and government agencies have suggested a wide array of metrics and thresholds for assessing and improving the quality of schedules. However, there is a gap in their focusing areas. This shows the necessity of having a comprehensive and organized list of metrics and thresholds to make good use of their best practices and recommendations for quality schedules. In addition, there is a need for identifying what schedule quality tests OFPC projects commonly passed and missed or what components of schedules OFPC needs to check additionally for sound baseline schedules for future OFPC projects.

Chapter 3: Research Methodology

In this chapter, the research methodology of this thesis is articulated. The research methodology consists of 8 steps; literature review, research questions and hypotheses, metric compilation and development, metrics selection, baseline schedule data collection and classification, schedule data evaluation by metrics, result analysis, and conclusions and recommendations. The flow chart of research methodology is provided below.

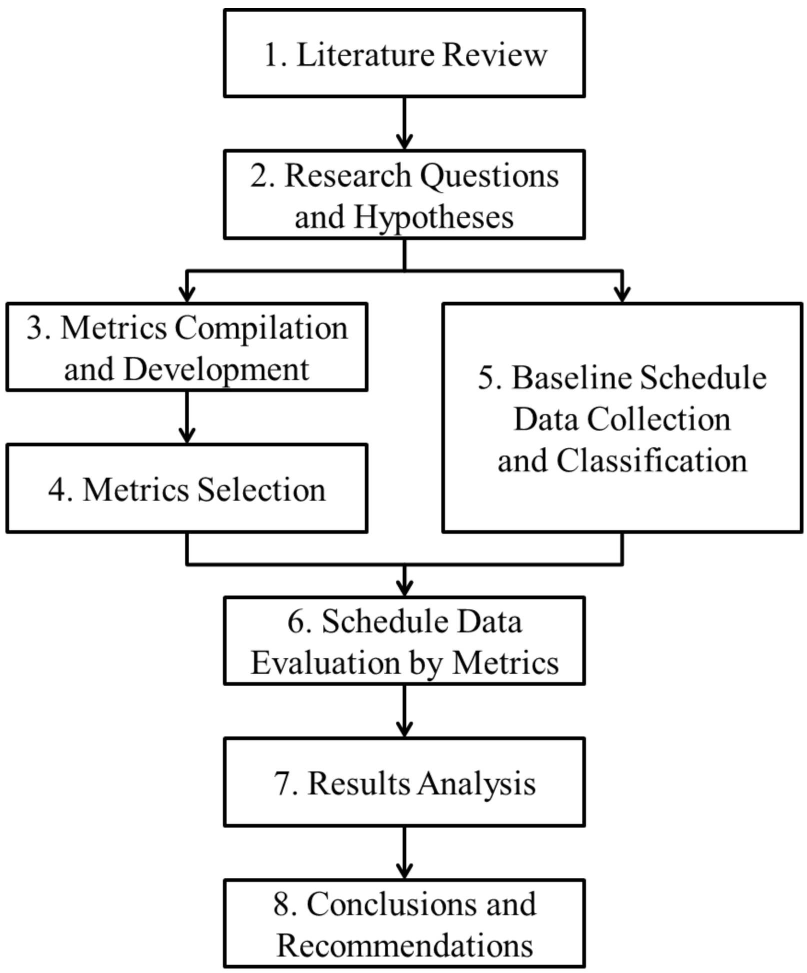

Figure 1. Research Methodology

As indicated above, literature review was conducted first to understand the importance and uses of baseline schedules and find out checklists or methods for improving their quality. Through the literature review, it was identified that many professional organizations and government agencies have suggested a wide array of metrics and thresholds for assessing and improving the quality of schedules. However, it was also identified that there is a gap in their focusing areas in terms of schedule components when evaluating schedules.

The literature review raised the first research question regarding a comprehensive and combined list of metrics and thresholds from diverse professional entities. The second question is about the evaluation results of baseline schedules used for OFPC projects by these metrics. Followed were research hypotheses regarding the practical use of the comprehensive list of the metrics and thresholds and informative findings from the evaluation results for future OFPC projects.

For developing a comprehensive and combined list of baseline schedule metrics and thresholds, metrics compilation and development were carried out and metrics selection came next to choose applicable ones in this research. In the meantime, baseline schedule data of OFPC projects was being collected for the application of the metrics. When metrics were sorted out and enough baseline schedule data of OFPC projects was collected, evaluating the schedule data by the metrics was performed and results were analyzed. Lastly, conclusions and recommendations based on the findings were made for future OFPC projects. Each step of the research methodology is explained in detail below.

3.1 LITERATURE REVIEW

For the literature review, various journals and technical papers from American Society of Civil Engineers (ASCE) and the Association for the Advancement of Cost Engineering International (AACEI) were reviewed and studied to understand the importance and uses of baseline schedules. In addition, a wide array of publications from diverse organizations including United States Government Accountability Office (GAO), National Defense Industrial Association (NDIA), Project Management Institute (PMI), and Defense Contract Management Agency (DCMA) has been reviewed to identify and understand their best practices and/or recommendations for quality schedules. Project Planning and Scheduling specifications of OFPC were also studied to understand their key provisions regarding baseline schedule submittals and to find out what needs to be checked additionally when they are reviewing submitted baseline schedules.

Through the literature review, it was identified that various government agencies and professional organizations have provided their best practices and/or recommendations for sound baseline schedules but it was found out that there is a gap in their focusing areas.

3.2 Research Questions and Hypotheses

The literature review raised the first research question regarding a comprehensive and combined list of schedule quality metrics and thresholds from diverse professional entities. The gap in their focusing areas when they are reviewing schedules indicates the necessity of having such a comprehensive and organized list of metrics and thresholds. It is assumed that this comprehensive list is a great tool or checklist to make good use of their best practices and/or recommendations for sound schedules.

The second question is about the evaluation results of baseline schedules used for OFPC projects by these metrics. To be more specific, there is a need to identify what schedule quality tests OFPC projects commonly passed and missed or what components of schedules OFPC needs to check additionally for evaluating and improving baseline schedules for future OFPC projects. A hypothesis behind these questions is that analysis on the schedule quality evaluation results will show what component of schedules should be improved or what metrics OFPC should pay attention to when reviewing and assessing baseline schedules for future projects.

3.3 Metrics Compilation and Development

To develop a comprehensive and combined list of baseline schedule quality metrics and thresholds, it was imperative to obtain decent sources for them, first. In this case, recommendations from professors in Construction Engineering and Project Management (CEPM) at the University of Texas at Austin, project managers, schedule forensic consultant, and owner representatives were the key to find sound sources.

Similar research papers were also studied to attain adequate references. Followed were reviewing and studying diverse publications regarding schedule quality best practices and/or recommendations from the decent sources including government agencies and professional organizations.

As a result, 11 publications from 10 organizations were chosen and extensively reviewed to compile and develop baseline schedule quality metrics and thresholds. Many metrics were suggested by these organizations while some were created based on schedule quality related concepts or recommended best practices. At the end, a wide array of metrics has been collected and developed and they are categorized into 9 groups. These 9 groups are named as follows; General, Milestone, Duration, Calendar, Logic, Constraint, Float, Lag, and Lead. In Chapter 5, the definition and equation of each metric are provided.

3.4 METRICS SELECTION

First of all, metrics without thresholds are excluded in this research since thresholds are considered as necessary to identify what metrics OFPC projects pass or fail to pass. Organizations reviewed for compiling and developing metrics provided their recommended thresholds for some metrics but not for all. Also, OFPC does not require resources related information in baseline schedules so that metrics regarding resources are neither dealt with in this thesis nor used in the evaluation process. When professional entities recommend a different value as a threshold for the same schedule quality metric, a stricter or more conservative threshold is chosen. Interviews with a Senior Project

Manager and Senior Program Controls Analyst at OFPC are followed to screen metrics and validate its thresholds. After screening baseline schedule quality metrics, 49 metrics are selected for this research.

3.5 Baseline Schedule Data Collection and Classification

When collecting baseline schedule data, OFPC's completed construction projects on the campus of the University of Texas at Austin were targeted. Also, the research focused on the baseline schedules that were submitted from contractors as a contract requirement and were approved by OFPC in an effort to contribute to evaluating schedule submittals and improving their quality for successful project management and completion. Software implemented for scheduling was not a criterion when schedule data was collected but all projects were developed in Primavera. Information on projects, such as contract type, contract value, and project type (e.g., a new facility or renovation project), was obtained, as well. In total, 13 baseline schedules are chosen and 8 out of 13 are for new facilities and the rest are for renovation projects.

3.6 Schedule Data Evaluation by Metrics

To perform the evaluation of schedule data by metrics, all the information of baseline schedules in Primavera files was exported into Excel, first. The following step was to sort out necessary information to apply metrics and edit it in the evaluation template. This process was repeated for each project. In the evaluation process, a variety of functions in Excel was used, for example, SUM, IF, COUNT, COUNTA, COUNTBLANK, COUNTIF, etc. With these functions, values were computed by metrics and they were compared with their thresholds. When the value of each metric satisfies its threshold, it is labeled as “Pass”. Otherwise, it is labeled as “Fail” in the result table of baseline schedule evaluation. The total number of “Pass” and “Fail” is summarized and tabulated in the result table, as well.

3.7 RESULTS ANALYSIS

The results of schedule quality evaluation are organized and analyzed in detail and research findings are summarized in result tables, which are located in the later chapter. The result tables contain information on each metric’s group, name, and threshold. Next to them, metric evaluation values and results of each project are presented. Metric evaluation results are indicated as “Pass” when a metric calculation result meets its threshold while they are labeled as “Fail” when it fails to meet its threshold. In the bottom of each table, the total number of “Pass” and “Fail” are summarized. The results analysis focuses on the metrics that schedules missed. As such, results analysis chapter starts with the metrics that all projects failed to pass and end with those that all projects passed. In other words, attention was mainly paid to the metrics that all or most schedules missed to identify what metric projects commonly failed to pass and what can be improved in the future projects.

3.8 CONCLUSIONS AND RECOMMENDATIONS

Based on the results, conclusions and suggestions are made for the purpose of contributing to facilitating the checking process of baseline schedules and improving their quality for successful construction projects. Due to the comparatively huge number of metrics utilized and projects collected, efforts have been made to focus on and deal with key findings in this chapter. As such, priorities were given to metrics that most projects failed to pass and/or that are relative to OFPC requirements for baseline schedule submittals. Based on the evaluation results and findings, diverse recommendations are made for key points to be checked and quality improvements in the baseline schedules of future OFPC projects.

Chapter 4: OFPC Projects Information

This chapter provides fundamental information of OFPC projects for which collected baseline schedules were used. To provide brief information on OFPC, this organization has been providing award winning program and project delivery solutions for the University of Texas institutions since 1965. Its services range from pre-project planning through warranty support. To be more specific, in addition to standard design and construction services, OFPC is renowned for providing contract management, engineering subject matter expert review of design documents and construction quality, development of owner's project requirements, program and project controls services, and more (OFPC 2015).

In terms of the fundamental projects information, it includes a contract type, an estimated duration, and estimated and approved total project cost (TPC) for each project. The graph below summarizes such information of 13 OFPC projects. As indicated below, blank bars represent the estimated durations of OFPC projects and solid bars indicate TPC at the time of Guaranteed Maximum Price (GMP) approval in US million dollars for each project. The estimated duration here indicates the gap between the early start date of "Notice to Proceed" and the early finish date of "Substantial Completion" and is calculated in calendar days. For example, Project 1's estimated duration from the early start of "Notice to Proceed" to the early finish of "Substantial Completion" was 951 calendar days and its TPC was 69.4 million US dollars.

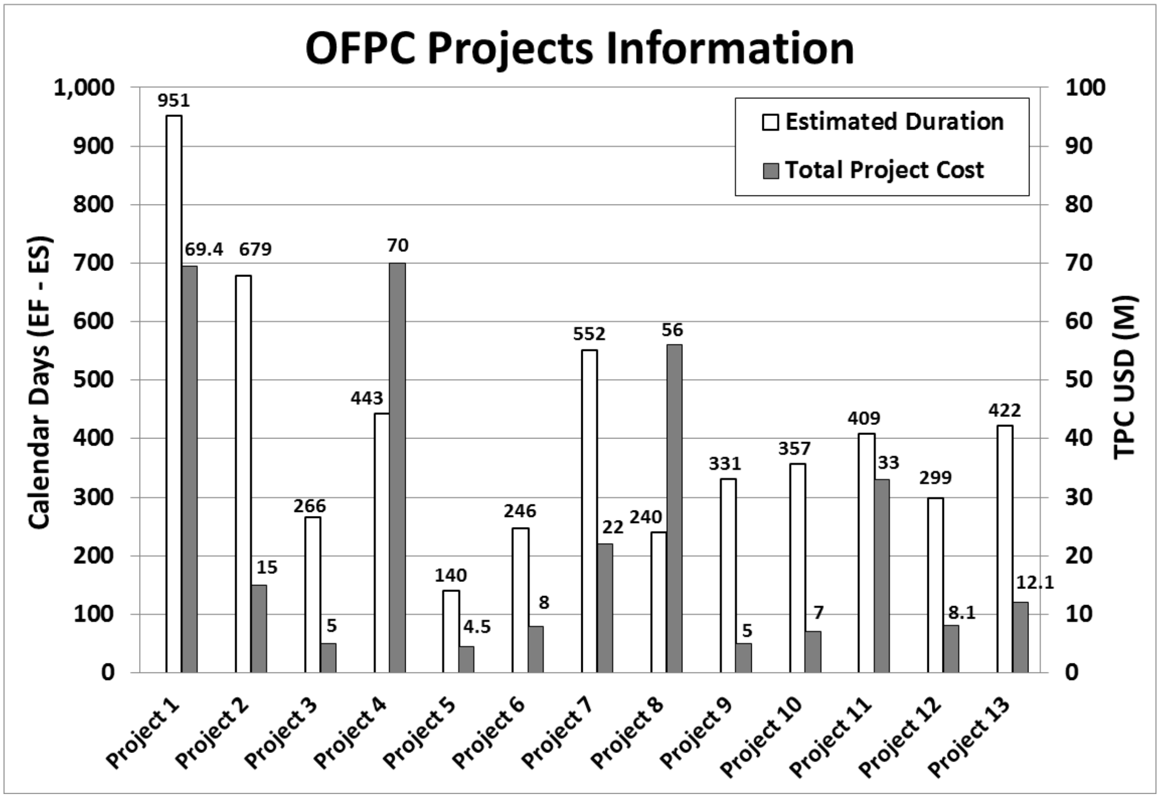

Figure 2. OFPC Projects Information

Identified information on OFPC projects is as follows;

- The project type of all the 13 OFPC projects is higher education.
- The contract type of all the13 OFPC projects is GMP.
- Project 1 through Project 8 is a new facility project while the rest of projects are renovation projects.
- The uses of new facilities include office, classroom, laboratory, museum, sports center, and student center.

- The scopes of renovation projects encompass fire sprinkler system installation, mechanical system replacement and maintenance, interior and exterior renovation, and life safety systems upgrade.
- Estimated project durations from the early start of "Notice to Proceed" through the early finish of "Substantial Completion" range from 140 to 951 calendar days.
- TPC of 13 OFPC projects are from 4.5 to 70 U.S. million dollars.
- The substantial completion dates of the OFPC projects above are between 2009 and 2013.

It is found out that all the 13 example projects had a liquidated damages provision. The values of liquidated damages per day are listed in the table below.

Project	Liquidated Damages ($/Day)
Project 1	2,000
Project 2	1,000
Project 3	1,000
Project 4	2,000
Project 5	1,000
Project 6	1,000
Project 7	2,000
Project 8	1,000
Project 9	2,000
Project 10	500
Project 11	4,000
Project 12	1,000
Project 13	4,000

Table 2. Liquidated Damages of OFPC Projects

For instance, the amount of liquidated damages of Project 1 is $2,000 per day. The summary of identified information on liquidated damages of OFPC projects are as follows;

- The highest amount of liquidated damages of the 13 OFPC projects is $4,000/day.
- The lowest amount of liquidated damages of the 13 OFPC projects is $500/day.
- The average amount of liquidated damages of the 13 OFPC projects is approximately $1,731/day.

Chapter 5: Findings

5.1 Schedule Quality Metrics

For collecting baseline schedule quality metrics and thresholds, the abovementioned 11 publications were extensively studied. The list of these 11 publications is provided in Chapter 2. As a result, 49 baseline schedule quality metrics are collected, developed, and used in this thesis. These metrics are divided into 9 groups; General, Milestone, Duration, Calendar, Logic, Constraint, Float, Lag, and Lead. The number of metrics in each group varies from 2 to 11. The categories of schedule quality metrics and number of metrics per category are represented in the table below.

No	Category		Metrics
1	Schedule Quality	General	11
2		Milestone	9
3		Duration	4
4		Calendar	3
5		Logic	10
6		Constraint	2
7		Float	5
8		Lag	3
9		Lead	2
	Total		**49**

Table 3. Category of Quantitative Schedule Quality Metrics

As seen in the table, 11 out of the total 49 metrics belong to the group “General” while 10 and 9 metrics are included in group “Logic” and “Milestone”, respectively.

Also, it is identified that group “Constraint” and “Lead” have the least number of metrics, which is 2. How each metric is calculated and why it is needed are explained in the following part of this thesis.

It is worth noting that the thresholds proposed by the abovementioned government agencies and professional organizations should not be considered as unquestionable but as suggested values. As such, it is recommended that each company or organization develops their own database from past projects and modifies the proposed thresholds to suit their specific conditions and needs (Moosavi and Moselhi 2012).

Category 1: General

Metrics for checking general information on schedules are categorized as General Metrics. In total, 11 General Metrics were identified from the literature review. Keywords for these General Metrics are ID, Task (Activity), Name, and Responsibility.

General 1 - Project ID

- Description: This metric checks if a project schedule has a unique numeric or text identification. A distinct project ID is necessary to distinguish and indicate a unique project. Using an equivalent ID for a different project should be avoided.
- Calculation: Does a project have a unique project ID?
- Threshold: Yes
- Reference: PMI 2007, OFPC 2011

General 2 - Project Name

- Description: This metric checks if a project schedule has a unique project name. A distinct project name is required to differentiate a project from others in a program. Using an identical project name for a different project should be avoided.
- Calculation: Does a project have a unique project name?
- Threshold: Yes
- Reference: PMI 2007, OFPC 2011

General 3 - Task ID (Unique)

- Description: This metric checks if every task has a unique ID. Distinct task IDs are necessary to identify a project and facilitate communication between project participants. It should be avoided to use the same task ID for different tasks. It is preferable to use a unique ID which can be automatically generated or follows a numbering scheme appropriate for the project.
- Calculation: $\frac{\text{The number of tasks using different task IDs}}{\text{The total number of tasks}}$
- Threshold: 100%
- Reference: PMI 2007, OFPC 2011, GAO 2012, NAV 2010

General 4 - Task Name (Unique)

- Description: This metric checks if every task has a unique name. Distinct names for detailed activities, summary activities, and milestones are imperative to identify each task and facilitate communication between project participants. It should be avoided to use the same task name for different tasks.

- Calculation: $\frac{\text{The number of tasks having unique names}}{\text{The total number of tasks}}$
- Threshold: 100%
- Reference: NDIA 2012, GAO 2012, NAV 2010, OFPC 2011

General 5 - Task Name (Descriptive Name)

- Description: This metric checks if every task has a descriptive name. Descriptive and clear names help project members to understand the scope of each activity. It is recommended to have a simple and consistent naming structure. Task descriptions shall start with a verb to describe what is to be done and end with location information.
- Calculation: $\frac{\text{The number of tasks having descriptive names}}{\text{The total number of tasks}}$
- Threshold: 100%
- Reference: NDIA 2012, GAO 2012, OFPC 2011

General 6 - WBS Element ID/Reference

- Description: This metric checks if a Work Breakdown Structure (WBS) ID is assigned to each task. A project schedule should assign to every task a WBS ID organized by project phase, stage, location, building, floor, area, elevation, system, etc. A numeric or text WBS ID is necessary to distinguish activities in one WBS group from those in different WBS groups.

- Calculation: $\frac{\text{The number of tasks having a WBS ID}}{\text{The total number of tasks}}$
- Threshold: 100%
- Reference: PMI 2007, NAV 2010, OFPC 2011

General 7 - Responsibilities Directory

- Description: This metric checks if a responsibilities directory is created for the assignment of responsibility codes for every project participant. It is necessary to have a responsibilities directory for the specification of accountabilities.
- Calculation: Is a responsibilities directory created?
- Threshold: Yes
- Reference: OFPC 2011, NAV 2010

General 8 - Responsibility Codes

- Description: This metric checks if responsibility codes are assigned to each task. It is necessary to assign a responsibility code to each task for the specification of work responsibilities. Responsibility codes may include contractor, subcontractor, fabricator, designer/engineer, owner, and other parties responsible for the accomplishment of their activities.
- Calculation: $\frac{\text{The number of tasks having a responsibility code}}{\text{The total number of tasks}}$

- Threshold: 100%
- Reference: OFPC 2011, NAV 2010

General 9 - Starting/Finishing Tasks on Weekend or Holiday

- Description: This metric checks if remaining tasks start or finish on a weekend or a holiday. This metric prevents tasks starting or ending on a weekend or holiday without permission. It helps create an accurate schedule and calculate a realistic ending date.
- Calculation: $\frac{\text{The number of tasks starting or ending on a weekend or holiday}}{\text{The total number of tasks}}$
- Threshold: 0%
- Reference: GAO 2012, OFPC 2011

General 10 - Level of Effort Task

- Description: This metric checks if a Level of Effort (LOE) activity is on the critical path. LOE activities represent effort that has no measurable output and cannot be related with a physical product or deliverable. These LOE activities include management and other oversight tasks that support detailed activities. Since they do not represent a discreet effort, LOE activities should not be on the critical path. In this research, LOE activities on the longest path were considered since a certain amount of total float was provided to each project as a cushion and management tracks the longest path.

- Calculation: $\frac{\text{The number of LOE tasks on the critical path}}{\text{The total number of tasks}}$
- Threshold: 0%
- Reference: DOD 2005, GAO 2012, NAV 2010

General 11 - Critical Path Length Index (CPLI)

- Description: This metric calculates Critical Path Length Index (CPLI). CPLI is an indicator of the efficiency or achievability of a project. In other words, CPLI measures how realistically a project will be completed on time, based on the remaining duration of the critical path and amount of total float available. CPLI is a ratio of the project critical path length plus the project total float to the project critical path length, where the critical path length indicates the time from the current status date to the end of the project. A CPLI more than 1.00 means that the schedule is efficient and will be accomplished on time while a CPLI less than 1.00 indicates that it is inefficient in terms of meeting the baseline date of the milestone or project. It is recommended that CPLI be at least 0.95 or 95% to sustain the efficiency of tasks on the critical path. Otherwise, additional effort may be required to avoid a schedule delay and achieve timely project completion. In this research, a ratio of the project longest path plus the project total float to the project longest path was computed for this metric evaluation.
- Calculation: $\mathrm{CPLI} = \frac{\text{Critical Path Length}+\text{Total Float}}{\text{Critical Path Length}}$
- Threshold: 95%

- Reference: DCMA 2012, NDIA 2012, DAU 2011, NAV 2010

Category 2: Milestone

Metrics for checking information regarding milestones are categorized as Milestone. The total 9 Milestone Metrics were collected from the literature review. The keywords for these Milestone Metrics are ratio, predecessor, and successor.

Milestone 1 - Ratio of Detail Tasks to Milestones

- Description: This metric calculates the ratio of detail tasks to milestones. It gives brief information regarding the level of planning detail of a schedule. A too low ratio of detail tasks to milestones would mean that the schedule is not planned in detail enough or makes milestones less meaningful. On the other hand, an extremely high ratio represents that a number of activities should be achieved for each milestone or the schedule is highly detailed. Both cases would make it challenging to record actual progress.
- Calculation: $\frac{\text{The number of detail tasks}}{\text{The total number of milestones}}$
- Threshold: Low <= 2, 10 <= High
- Reference: GAO 2012

Milestone 2 - Milestones Missing Predecessor or Successor

- Description: This metric checks if milestones are missing a predecessor or successor except for the first start milestone and last finish milestone that do not have a predecessor and successor respectively. Another exception would be milestones for information or scheduled events, such as the start or end of a semester. Milestones missing a predecessor or successor will not reflect the impact of task delays or acceleration accurately.
- Calculation: $\frac{\text{The number of milestones missing a predecessor or successor}}{\text{The total number of milestones}}$
- Threshold: 0%
- Reference: NDIA 2012, GAO 2012, OFPC 2011

Milestone 3 - Milestones Missing Predecessor and Successor

- Description: This metric checks if milestones are missing both a predecessor and successor. A milestone simply for the purpose of information can be exceptional. As milestones missing a predecessor and successor will not reflect the impact of task delays or acceleration accurately, their missing logics should be justified.
- Calculation: $\frac{\text{The number of milestones missing a predecessor and successor}}{\text{The total number of milestones}}$
- Threshold: 0%
- Reference: NDIA 2012, GAO 2012, OFPC 2011

Milestone 4 - Milestones Missing Predecessor

- Description: This metric checks if milestones have at least one predecessor. The first start milestone that misses a predecessor but starts a schedule will be exceptional. As milestones missing a predecessor will not reflect the impact of task delays or acceleration accurately, their missing logics should be justified.
- Calculation: $\frac{\text{The number of milestones missing a predecessor}}{\text{The total number of milestones}}$
- Threshold: 0%
- Reference: NDIA 2012, GAO 2012, OFPC 2011

Milestone 5 - Milestones Missing Successor

- Description: This metric checks if milestones have at least successor. The last finish milestone that misses a successor but finishes a schedule will be exceptional. As milestones missing a successor will not reflect the impact of task delays or acceleration accurately, their missing logics should be justified.
- Calculation: $\frac{\text{The number of milestones missing a succesor}}{\text{The total number of milestones}}$
- Threshold: 0%
- Reference: NDIA 2012, GAO 2012, OFPC 2011

Milestone 6 - Milestones with Resources

- Description: This metric checks if milestones have resources. Milestones are used to indicate the accomplishment or realization of key events in a schedule so that they should not have resources.
- Calculation: $\frac{\text{The number of milestones having resources}}{\text{The total number of milestones}}$
- Threshold: 0%
- Reference: NDIA 2012, PMI 2007, GAO 2012

Milestone 7 - Milestones with Duration

- Description: This metric checks if milestones have durations. Milestones are used to indicate the accomplishment or realization of key events in a schedule so that they should not have durations.
- Calculation: $\frac{\text{The number of milestones having durations}}{\text{The total number of milestones}}$
- Threshold: 0%
- Reference: DCMA 2012, NDIA 2012, PMI 2007, GAO 2012, OFPC 2011

Milestone 8 - Start and Finish Milestones having a start or finish date

- Description: This metric checks if milestones have a clear start or finish date. Since milestones indicate the start and/or finish of an interim step or event, every milestone should have a clearly determined start or finish date. Start milestones may have a start date while finish milestones will have a finish date.

- Calculation: $\frac{\text{The number of milestones having a start or finish date}}{\text{The total number of milestones}}$
- Threshold: 100%
- Reference: NDIA 2012, PMI 2007, GAO 2012

Milestone 9 - Tasks Marked both as a Milestone and Summary Task

- Description: This metric checks if tasks are indicated as both a milestone and summary task. Milestones are used to indicate the accomplishment or realization of key events in a schedule while summary tasks are grouping elements that show the total duration required to complete their lower-level activities. Summary tasks are different from milestones in terms of duration and logic relationship. Summary activities should not have logic relationships so that their durations are calculated by their lower-level activities.
- Calculation: $\frac{\text{The number of tasks marked as both a milestone and summary task}}{\text{The total number of tasks}}$
- Threshold: 0%
- Reference: GAO 2012

Category 3: Duration

The metrics for checking information regarding duration are categorized as Duration. The total 4 Duration Metrics were identified from the literature review. The keywords for these Duration Metrics are unit, extreme, and maximum.

Duration 1 - Dissimilar Time Units

- Description: This metric checks if all the activities are using the same unit for their durations, preferably days. It will reduce confusion and improve communication between project members. For this reason, durations should be represented with one unit.
- Calculation: Is the schedule using the same duration time unit?
- Threshold: Yes
- Reference: NDIA 2012, GAO 2012

Duration 2 - High Duration

- Description: This metric checks if incomplete detailed activities have durations longer than 44 working days. High durations of activities indicate that they are too broad for appropriate planning and controls. Unless proper explanations are provided, it is recommended to break down detailed activities having such high durations into more detailed and manageable-sized activities for better controls. Certain activities may span more than 44 working days. Exceptions are summary-level schedules, generally developed before detailed engineering in completed, as well as LOE activities whose duration are dependent on their underlying discrete efforts.

- Calculation:

$$\frac{\text{The number of incomplete tasks whose durations are longer than 44 work days}}{\text{The total number of incomplete tasks}}$$

- Threshold: 5%
- Reference: DOD 2005, DCMA 2012, NDIA 2012, PMI 2007, GAO 2012, CEVM 2008, NAV 2010

Duration 3 - Extreme Duration

- Description: This metric checks if incomplete detailed activities have durations longer than 125 working days. Extreme durations of activities indicate that they are too broad for appropriate planning and controls. Unless proper explanations are provided, it is recommended to break down detailed activities having such extreme durations into more detailed and manageable-sized activities for better controls.
- Calculation:

$$\frac{\text{The number of incomplete tasks whose durations are longer than 125 work days}}{\text{The total number of incomplete tasks}}$$

- Threshold: 0%
- Reference: NAV 2010

Duration 4 - Maximum Duration Limit (30 Days)

- Description: This metric checks if incomplete detailed activities have the duration of 30 working days or below. All the durations of activities should not exceed 30 days for better planning and controls. Unless proper explanations are provided, it is recommended to break down detailed activities whose durations are more than 30 working days into more detailed and manageable-sized activities for better controls.
- Calculation:

$$\frac{\text{The number of incomplete tasks whose durations are longer than 30 work days}}{\text{The total number of incomplete tasks}}$$

- Threshold: 100%
- Reference: OFPC 2011

Category 4: Calendar

The metrics for checking information regarding calendar are categorized as Calendar. The total 3 Calendar Metrics were identified from the literature review. The keywords for these Calendar Metrics are working and holiday.

Calendar 1 - Working Calendars

- Description: This metric checks if a calendar represents work period or duration in days or hours and helps calculate proper start and finish times based on task durations and resource loads. As a calendar specifies valid working durations for activities and resources, an adequate time unit should be utilized throughout a project.

- Calculation: Are work periods represented with days or hours? ➔ Yes or No
- Threshold: Yes
- Reference: NDIA 2012, GAO 2012

Calendar 2 - Project Calendar

- Description: This metric checks if a project is scheduled based on a customized or proper calendar. A project calendar should be used for the right project.
- Calculation: Is there a project calendar? ➔ Yes or No
- Threshold: Yes
- Reference: NDIA 2012, PMI 2007, GAO 2012, NAV 2010

Calendar 3 - Holidays

- Description: This metric checks if a project calendar is taking into account holidays and other exceptions. It is necessary to consider holidays in a calendar to calculate precise work duration. The examples of holidays would be New Year's Day, Memorial Day, Labor Day, Thanksgiving, Christmas Eve, Christmas, and New Year's Eve.
- Calculation: Are holidays and exceptions considered in a project calendar? ➔ Yes or No
- Threshold: Yes
- Reference: NDIA 2012, OFPC 2011, GAO 2012, NAV 2010

Category 5: Logic

The metrics for checking information regarding logics in a schedule are categorized as Logic. The total 10 Logic Metrics were identified from the literature review. The keywords for Logic Metrics are open ends, predecessor, successor, and relationship type.

Logic 1 - Basic Relationship (Open Ends)

- Description: This metric identifies the number of activities missing logic relationships and calculate the ratio of relevant activities to the total. Every activity within a schedule should have at least one predecessor and one successor except for the first start and last finish task. For instance, when a schedule starts with a start milestone, Notice to Proceed, it may not have a predecessor but at least one successor. At the same time, when a project finishes with a finish milestone, Substantial Completion, it may not have a successor. It is important not to have missing logics for articulating dependencies between activities and calculating the accurate total duration required to complete the project.
- Calculation: $\frac{\text{The number of tasks missing a predeceesor or successor}}{\text{The total number of tasks}}$
- Threshold: 0% (Exclude exceptions)
- Reference: DOD 2005, DCMA 2012, NDIA 2012, PMI 2007, OFPC 2011, GAO 2012, DOD 2012, CVEM 2008, NAV 2010 (5%)

Logic 2 - Missing Predecessor

- Description: This metric identifies the number of activities missing a predecessor and computes the ratio of relevant activities to the total. It is necessary to have at least one predecessor for articulating a dependency and logic relationship between activities. The first activity in a schedule will be exceptional.
- Calculation: $\frac{\text{The number of tasks missing a predeceesor}}{\text{The total number of tasks}}$
- Threshold: 5%
- Reference: NDIA 2012, PMI 2007, GAO 2012, DOD 2012, NASA 2010, OFPC 2011

Logic 3 - Missing Successor

- Description: This metric identifies the number of activities missing a successor and computes the ratio of relevant activities to the total. It is necessary to have at least one successor for articulating a dependency and logic relationship between activities. The last activity in a schedule will be exceptional.
- Calculation: $\frac{\text{The number of tasks missing a successor}}{\text{The total number of tasks}}$
- Threshold: 5%
- Reference: NDIA 2012, PMI 2007, GAO 2012, DOD 2012, NASA 2010, NAV 2010, OFPC 2011

Logic 4 - Relationship Type (Finish to Start)

- Description: This metric identifies the number of Finish to Start (FS) relationships between activities in the schedule and computes the ratio of the FS logics to the total number of logics. It is recommended to use FS relationship since it explicitly describes a dependency between activities and leads to a clear and logical path throughout the schedule.
- Calculation: $\frac{\text{The number of FS relationships between activities}}{\text{The total number of links}}$
- Threshold: 90%
- Reference: DOD 2005, DCMA 2012, NDIA 2012, PMI 2007, GAO 2012, NAV 2010 (80%)

Logic 5 - Circular Logics

- Description: This metric checks if there is a circular logic in the schedule. A circular logic causes a loop of activities in the schedule that negatively impacts on the calculation of the total duration.
- Calculation: $\frac{\text{The number of links in circular logics}}{\text{The total number of links}}$
- Threshold: 0%
- Reference: DOD 2005, NDIA 2012, GAO 2012, NASA 2010, OFPC 2011

Logic 6 - Critical Path Test (Horizontal Traceability)

- Description: This metric checks the integrity of a project's critical path. If a project completion date is not delayed in proportion to the amount of intentional slip that is introduced on a critical activity as a part of this test, then it is assumed that the project has a broken logic in the schedule. In other words, it should be identified that the final critical activity in the schedule is delayed by the approximate number of delays added to the critical path intentionally. The intentional slip on the critical activity should be greater than its available total float to see the delay. In this research, an intentional slip was given to one of activities on the longest path since a certain amount of total float was provided to each project as a cushion and management tracks the longest path.
- Calculation: When the duration of any activity on the critical path is increased by a random amount, does the critical path length increase in proportion to that amount?
- Threshold: Yes
- Reference: DOD 2005, DCMA 2012, NDIA 2012, PMI 2007, OFPC 2011, GAO 2012, DOD 2012, NAV 2010

Logic 7 - Percentage of Tasks on Critical Path

- Description: This metric identifies the number of activities on the critical path and computes the ratio of relevant activities to the total. This metric helps check if the number of activities on the critical path is appropriate enough to give an assurance that the schedule is not overly serial and simplified but practical. In this research, tasks on the longest path were considered since a certain amount of total float was provided to each project as a cushion and management tracks the longest path.

- Calculation: $\frac{\text{The number of activities on the critical path}}{\text{The total number of activities}}$
- Threshold: 15~20%
- Reference: DOD 2005

Logic 8 - Link in Summary Task

- Description: This metric identifies the number of activities linked with summary tasks as a predecessor or successor and computes the ratio of relevant activities to the total. Summary activities should not have logic relationships because their start and finish dates are derived from lower-level detailed activities. As such, it is important to assign predecessors and successors at the detail tasks level.
- Calculation: $\frac{\text{The number of activities linked with summary tasks}}{\text{The total number of activities}}$
- Threshold: 0%
- Reference: NDIA 2012, GAO 2012, NASA 2010

Logic 9 - Link in Hammock

- Description: Hammocks are used to give a summary of lower-level activities. In other words, they give a summary of schedule information on duration and dates (e.g., finish dates). It is recommended that hammocks should not drive successor logic.

- Calculation: $\frac{\text{The number of hammocks driving successor logic}}{\text{The total number of hammocks}}$
- Threshold: 0%
- Reference: NDIA 2012, GAO 2012

Logic 10 - Link in Level of Effort

- Description: Level of Effort (LOE) tasks enable budget allocation throughout the schedule to manage efforts with no measurable output, product, or activity. Schedule performance on these LOE tasks is measured by the passage of time based on the baseline. LOE tasks should not be logically linked to drive discrete work. Also, the duration of LOE activities should be determined by the overall duration of the discrete work they support. Therefore, an LOE activity should not have any successor. Incorrect logic application on LOE can cause inaccurate calculations of the schedule's total float and critical path.
- Calculation: $\frac{\text{The number of tasks linked to LOE tasks as a successor}}{\text{The total number of links}}$
- Threshold: 0%
- Reference: NDIA 2012, GAO 2012, NAV 2010

Category 6: Constraint

The metrics for checking schedule information on constraint are categorized as Constraints Metrics. The total 2 Constraints Metrics were identified from the literature review. The keywords for Constraints Metrics are hard constraint and number.

Constraint 1 - Hard Constraints

- Description: This metric identifies the number of activities with a hard constraint, for example, Must-Finish-On (MFO), Must-Start-On (MSO), Start-No-Later-Than (SNLT), and Finish-No-Later-Than (FNLT), and computes the ratio of relevant activities to the total. This metric helps create a logic-driven schedule since hard constraints prevent activities from being relocated by their dependencies and, consequently, cause illogical schedules. Sometimes, late finish constraints are allowed for contractually last activities, such as Substantial Completion or Final Completion milestone. Otherwise, a legitimate reason is required to constrain an activity.
- Calculation: $\frac{\text{The number of activities with a hard constraint}}{\text{The total number of activities}}$
- Threshold: 0%
- Reference: DOD 2005, DCMA 2012(5%), NDIA 2012, PMI 2007, OFPC 2011 (0%), GAO 2012, NAV 2010, GEVM 2008 (0%)

Constraint 2 - No. Constraints

- Description: This metric identifies the number of activities with a constraint and computes the ratio of relevant activities to the total. It is recommended to minimize the use of constraints to ensure that the network logic is not influenced.
- Calculation: $\frac{\text{The number of activities with a constraint}}{\text{The total number of activities}}$

- Threshold: 10%
- Reference: DOD 2012(15% but can’t find), NASA 2010 (10%), CEVM 2008 (5%)

Category 7: Float

The metrics for checking information regarding float are categorized as Float Metrics. Total 5 Float Metrics were identified from the literature review. The keywords for Float Metrics are contingency, high, and maximum.

Float 1 - Total Float Contingency

- Description: This metric calculates the ratio of total float on the critical path and the total duration of a project. It is required to have at least 10% of the total duration of the project from “Notice to Proceed (NTP)” to “Substantial Completion” as total float. Total float should not be indicated as a single activity but rather should be calculated as the difference between the early and late start or early and late finish dates of each task. In this research, total float on the longest path was considered since a certain amount of total float was provided to each project as a cushion and management tracks the longest path.
- Calculation: $\frac{\text{Total float on the critical path}}{\text{Total project duation from Notice to Proceed to Substantial Completion}}$
- Threshold: 10%
- Reference: OFPC 2011, GAO 2012

Float 2 - High Total Float

- Description: This metric identifies incomplete activities with total float greater than 44 working days and computes the ratio of relevant activities to the total incomplete activities. The publications chose the value of 44 working days since it represents 2 months. It is possible that high total float over 44 working days is caused by missing processors and/or successors. As such, this metric helps prevent an unstable or logic-broken schedule. Another indication of high float is that certain activities can be executed at any time during the project.
- Calculation: $\frac{\text{The number of incomplete activities with total float over 44 work days}}{\text{The total number of incomplete activities}}$
- Threshold: 5%
- Reference: DOD 2005, DCMA 2012, NDIA 2012, GAO 2012, CEVM 2008, NAV 2010.

Float 3 - Extreme Total Float

- Description: This metric identifies incomplete activities with total float greater than 120 working days and computes the ratio of relevant activities to the total incomplete activities. It is possible that extreme total float over 120 working days is caused by missing processors and/or successors. This metric helps prevent an unstable or logic-broken schedule.
- Calculation: $\frac{\text{The number of incomplete activities with total float over 120 work days}}{\text{The total number of incomplete activities}}$

- Threshold: 0%
- Reference: NDIA 2012

Float 4 - Negative Total Float

- Description: This metric identifies the number of incomplete activities with negative float and computes the ratio of relevant activities to total incomplete activities. This metric helps identify activities that delay the completion of one or more milestones. It is recommended to have an explanation or corrective action for activities with negative float. It is known that constraints cause negative float.
- Calculation: $\frac{\text{The number of incomplete activities with negative float}}{\text{The total number of incomplete activities}}$
- Threshold: 0%
- Reference: DOD 2005, DCMA 2012, NDIA 2012, PMI 2007, GAO 2012, DOD 2012, NAV 2010

Float 5 - Maximum Total Float

- Description: This metric identifies the number of incomplete activities with total float longer than the sum of the minimum total float on the longest path and 45 days and computes the ratio of relevant activities to the total incomplete activities. It is recommended that no activities have total float greater than the minimum total float identified by the longest path plus 45 days.

- Calculation:

$$\frac{\text{The number of incomplete activities with TF greater than the minimum TF on longest path+45 days}}{\text{The total number of incomplete activities}}$$

- Threshold: 0%
- Reference: NDIA 2012, OFPC 2011

Category 8: Lag

The metrics for checking information regarding lag are categorized as Lag Metrics. The total 2 Lag Metrics were identified from the literature review. The keywords for Lag Metrics are number and resources.

Lag 1 - Number of Lags

- Description: This metric identifies the number of lags in relationships between incomplete activities and their predecessors and computes the ratio of the number of lags in predecessor logic relationships to the total number of links that incomplete activities have with their predecessors. The use of lags helps reduce the number of activities. However, lags do not provide detailed information on them so that the use of lags should be carefully reviewed when managing a schedule. Also, it is recommended that lags should not replace activities with resources since they cannot be monitored with ease as well as cannot have resources.
- Calculation:

$$\frac{\text{The number of lags in links between incomplete activities and their predecessors}}{\text{The total number of links between incomple activities and their predecessors}}$$

- Threshold: 5%
- Reference: DOD 2005, DCMA 2012, PMI 2007, GAO 2012, NAV 2010

Lag 2 - Lags with Resources

- Description: This metric identifies the number of lags with resources in the schedule and computes the ratio of relevant lags to total links between activities. Lags indicate the passage of time with no effort or resources. In the case that lags have resources, they should be represented as an activity.
- Calculation: $\frac{\text{The number of lags with resources}}{\text{The total number of links between activities}}$
- Threshold: 0%
- Reference: PMI 2007, GAO 2012

Lag 3 - Long Lags

- Description: This metric identifies the number of lags bigger than 30 working days and computes the ratio of relevant lags to the total links between activities. Since lags do not provide detailed information on them or contain risks, it is beneficial to check if there is any lag bigger than 30 working days when managing the schedule. If so, it is necessary to add an activity instead of using a long lag to provide more detailed information.
- Calculation: $\frac{\text{The number of lags bigger than 30 work days}}{\text{The total number of links between activities}}$
- Threshold: 0%

- Reference: DOD 2005, NAV 2010

Category 9: Lead

The metrics for checking information regarding lead are categorized as Lead Metrics. Total 2 Lead Metrics were developed from the literature review. The keywords for Lead Metrics are number and resources.

Lead 1 - Number of Lead

- Description: This metric identifies the number of leads, also known as negative lags, in relationships between incomplete activities and their predecessors and computes the ratio of the number of leads to that of the relationships that incomplete activities have with their predecessors. Generally speaking, it is hard to demonstrate negative time. Also, leads may distort total float in the schedule as well as cause resources conflicts. As such, it is recommended to avoid using them. Alternatively, leads can be replaced by a positive lag on a Start to Start relationship.
- Calculation:

$$\frac{\text{The number of leads in links between incomplete activities and their predecessors}}{\text{The total number of links between incomple activities and their predecessors}}$$

- Threshold: 0%
- Reference: DOD 2005, DCMA 2012, PMI 2007, GAO 2012, NAV 2010

Lead 2 - Leads with Resources

- Description: This metric identifies the number of leads or negative lags with resources in the schedule and computes the ratio of the number of such leads to that of the relationships between activities. Leads have an impact on a logical relationship by imposing acceleration in the start of finish of a successor task. As such, it is recommended to avoid using leads, not to mention assigning resources to them.
- Calculation: $\frac{\text{The number of leads with resources}}{\text{The total number of links between activities}}$
- Threshold: 0%
- Reference: PMI 2007, GAO 2012

5.2 RESULTS OF OFPC PROJECTS EVALUATION

Tables of OFPC Projects Evaluation Results

The results of OFPC projects evaluation by metrics are summarized in the below tables. The tables contain the information on the category, name, and threshold of each metric and the evaluation results of projects.

Group	Metric	Threshold	Project 1 (New)		Project 2 (New)		Project 3 (New)		Project 4 (New)		Project 5 (New)	
			Value	Result	Value	Result	Value	Result	Value	Result	Value	Result
General 1	Project ID	YES	YES	Pass	YES	Pass	YES	Pass	YES	Pass	YES	Pass
General 2	Project Name	YES	YES	Pass	YES	Pass	YES	Pass	YES	Pass	YES	Pass
General 3	Task ID (Unique)	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 4	Task Name (Unique)	100%	90.83%	Fail	77.78%	Fail	92.65%	Fail	100.00%	Pass	100.00%	Pass
General 5	Task Name (Descriptive Name)	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 6	WBS Element ID/Reference	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 7	Responsibility/Organizational/Functional Directory	Yes	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
General 8	Responsibility/Organizational/Functional Codes	100%	86.37%	Fail	100.00%	Pass	2.04%	Fail	100.00%	Pass	0.00%	Fail
General 9	Starting Tasks on Weekend or Holiday	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
General 10	Level of Effort Task	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	3.33%	Fail	0.00%	Pass
General 11	Critical Path Length Index (CPLI)	95%	110.78%	Pass	110.19%	Pass	110.68%	Pass	101.55%	Pass	130.85%	Pass
Milestone 1	Ratio of Detail Tasks to Milestones	Low<=2, 10<=High	14.23	Fail	1.84	Fail	10.67	Fail	2.66	Pass	6.44	Pass
Milestone 2	Milestones Missing Predecessor or Successor	0%	0.00%	Pass	2.63%	Fail	0.00%	Pass	10.34%	Fail	0.00%	Pass
Milestone 3	Milestones Missing Predecessor and Successor	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 4	Milestones Missing Predecessor	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	10.34%	Fail	0.00%	Pass
Milestone 5	Milestones Missing Successor	0%	0.00%	Pass	2.63%	Fail	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 6	Milestones with Resources	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 7	Milestones with Duration	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 8	Start and Finish Milestones	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
Milestone 9	Tasks Marked both Milestone and Summary Task	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Duration 1	Dissimilar Time Units	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Duration 2	High Duration	5%	1.07%	Pass	8.70%	Fail	2.63%	Pass	1.28%	Pass	1.72%	Pass
Duration 3	Extreme Duration	0%	0.00%	Pass	2.17%	Fail	0.00%	Pass	0.00%	Pass	0.00%	Pass
Duration 4	Maximum Duration Limit (30 Days)	100%	98.26%	Fail	84.78%	Fail	95.79%	Fail	96.15%	Fail	96.55%	Fail
Calendar 1	Working Calendars	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Calendar 2	Project Calendar	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Calendar 3	Holidays	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Logic 1	Basic Relationship (Open Ends)	0%	0.00%	Pass	1.85%	Fail	0.00%	Pass	3.74%	Fail	0.00%	Pass
Logic 2	Missing Predecessor	5%	0.00%	Pass	0.00%	Pass	0.00%	Pass	3.74%	Pass	0.00%	Pass
Logic 3	Missing Successor	5%	0.00%	Pass	1.85%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 4	Relationship Type (Finish to Start)	90%	71.78%	Fail	97.06%	Pass	89.82%	Fail	82.56%	Fail	84.68%	Fail
Logic 5	Circular Logics	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 6	Critical Path Test	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Logic 7	Percentage of Tasks on Critical Path	15~20%	16.48%	Pass	35.19%	Fail	34.69%	Fail	28.04%	Fail	19.40%	Pass
Logic 8	Link in Summary Task	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 9	Link in Hammock	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 10	Link in Level of Effort	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.51%	Fail	0.00%	Pass
Constraint 1	Hard Constraints	0%	0.00%	Pass	0.00%	Pass	0.82%	Fail	0.93%	Fail	0.00%	Pass
Constraint 2	No of Constraints	10%	0.00%	Pass	0.00%	Pass	1.63%	Pass	11.21%	Fail	0.00%	Pass
Float 1	Total Float Contingency	10%	11.20%	Pass	9.23%	Fail	11.89%	Pass	1.64%	Fail	30.85%	Pass
Float 2	High Total Float	5%	100.00%	Fail	68.25%	Fail	19.80%	Fail	48.60%	Fail	14.93%	Fail
Float 3	Extreme Total Float	0%	55.15%	Fail	28.57%	Fail	1.52%	Fail	14.02%	Fail	0.00%	Pass
Float 4	Negative Total Float	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Float 5	Maximum Total Float	0%	56.67%	Fail	57.14%	Fail	3.05%	Fail	40.19%	Fail	0.00%	Pass
Lag 1	No. of Lags	5%	12.59%	Fail	7.69%	Fail	7.53%	Fail	5.67%	Fail	0.00%	Pass
Lag 2	Lags with Resources	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Lag 3	Long Lags	5%	0.07%	Pass	2.21%	Pass	0.25%	Pass	1.03%	Pass	0.00%	Pass
Lead 1	No. of Lead	0%	0.00%	Pass	1.28%	Fail	0.00%	Pass	5.67%	Fail	0.00%	Pass
Lead 2	Leads with Resources	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass

Pass	40	**Pass**	34	**Pass**	38	**Pass**	33	**Pass**	45
Fail	9	**Fail**	15	**Fail**	11	**Fail**	16	**Fail**	4
Total	49	**Total**	49	**Total**	49	**Total**	49	**Total**	49

Table 4. Results of OFPC Projects Evaluation by Metrics - 1

Group	Metric	Threshold	Project 6 (New)		Project 7 (New)		Project 8 (Reno)		Project 9 (Reno)	
			Value	Result	Value	Result	Value	Result	Value	Result
General 1	Project ID	YES	YES	Pass	YES	Pass	YES	Pass	YES	Pass
General 2	Project Name	YES	YES	Pass	YES	Pass	YES	Pass	YES	Pass
General 3	Task ID (Unique)	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 4	Task Name (Unique)	100%	98.10%	Fail	100.00%	Pass	98.66%	Fail	75.63%	Fail
General 5	Task Name (Descriptive Name)	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 6	WBS Element ID/Reference	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 7	Responsibility/Organizational/Functional Directory	Yes	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
General 8	Responsibility/Organizational/Functional Codes	100%	99.53%	Fail	100.00%	Pass	100.00%	Pass	93.28%	Fail
General 9	Starting Tasks on Weekend or Holiday	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
General 10	Level of Effort Task	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
General 11	Critical Path Length Index (CPLI)	95%	109.90%	Pass	110.36%	Pass	109.57%	Pass	109.80%	Pass
Milestone 1	Ratio of Detail Tasks to Milestones	Low<=2, 10<=High	10.72	Fail	9.00	Pass	1.99	Fail	12.22	Fail
Milestone 2	Milestones Missing Predecessor or Successor	0%	5.56%	Fail	0.00%	Pass	1.00%	Fail	11.11%	Fail
Milestone 3	Milestones Missing Predecessor and Successor	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 4	Milestones Missing Predecessor	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	11.11%	Fail
Milestone 5	Milestones Missing Successor	0%	5.56%	Fail	0.00%	Pass	1.00%	Fail	0.00%	Pass
Milestone 6	Milestones with Resources	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 7	Milestones with Duration	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 8	Start and Finish Milestones	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
Milestone 9	Tasks Marked both Milestone and Summary Task	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Duration 1	Dissimilar Time Units	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Duration 2	High Duration	5%	1.08%	Pass	2.30%	Pass	6.19%	Fail	0.00%	Pass
Duration 3	Extreme Duration	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Duration 4	Maximum Duration Limit (30 Days)	100%	98.38%	Fail	93.68%	Fail	90.72%	Fail	94.95%	Fail
Calendar 1	Working Calendars	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Calendar 2	Project Calendar	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Calendar 3	Holidays	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Logic 1	Basic Relationship (Open Ends)	0%	1.42%	Fail	0.87%	Fail	1.34%	Fail	4.20%	Fail
Logic 2	Missing Predecessor	5%	0.47%	Pass	0.43%	Pass	0.33%	Pass	1.68%	Pass
Logic 3	Missing Successor	5%	0.95%	Pass	0.43%	Pass	1.00%	Pass	2.52%	Pass
Logic 4	Relationship Type (Finish to Start)	90%	85.48%	Fail	92.04%	Pass	87.89%	Fail	87.22%	Fail
Logic 5	Circular Logics	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 6	Critical Path Test	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Logic 7	Percentage of Tasks on Critical Path	15~20%	13.27%	Fail	25.65%	Fail	10.70%	Fail	39.50%	Fail
Logic 8	Link in Summary Task	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 9	Link in Hammock	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 10	Link in Level of Effort	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Constraint 1	Hard Constraints	0%	2.37%	Fail	0.00%	Pass	0.00%	Pass	0.00%	Pass
Constraint 2	No of Constraints	10%	2.37%	Pass	0.00%	Pass	1.00%	Pass	0.00%	Pass
Float 1	Total Float Contingency	10%	11.90%	Pass	11.38%	Pass	10.91%	Pass	11.01%	Pass
Float 2	High Total Float	5%	12.24%	Fail	75.90%	Fail	12.13%	Fail	22.64%	Fail
Float 3	Extreme Total Float	0%	0.00%	Pass	0.00%	Pass	2.57%	Fail	0.94%	Fail
Float 4	Negative Total Float	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Float 5	Maximum Total Float	0%	2.55%	Fail	0.51%	Fail	6.62%	Fail	1.89%	Fail
Lag 1	No. of Lags	5%	5.43%	Fail	10.15%	Fail	25.43%	Fail	8.54%	Fail
Lag 2	Lags with Resources	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Lag 3	Long Lags	5%	0.00%	Pass	0.27%	Pass	3.36%	Pass	0.00%	Pass
Lead 1	No. of Lead	0%	0.00%	Pass	0.00%	Pass	4.16%	Fail	3.66%	Fail
Lead 2	Leads with Resources	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass

Pass	36	**Pass**	43	**Pass**	35	**Pass**	35
Fail	13	**Fail**	6	**Fail**	14	**Fail**	14
Total	49	**Total**	49	**Total**	49	**Total**	49

Table 5. Results of OFPC Projects Evaluation by Metrics - 2

Group	Metric	Threshold	Project 10 (Reno)		Project 11 (Reno)		Project 12 (Reno)		Project 13 (Reno)	
			Value	Result	Value	Result	Value	Result	Value	Result
General 1	Project ID	YES	YES	Pass	YES	Pass	YES	Pass	YES	Pass
General 2	Project Name	YES	YES	Pass	YES	Pass	YES	Pass	YES	Pass
General 3	Task ID (Unique)	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 4	Task Name (Unique)	100%	96.88%	Fail	86.54%	Fail	100.00%	Pass	97.24%	Fail
General 5	Task Name (Descriptive Name)	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 6	WBS Element ID/Reference	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 7	Responsibility/Organizational/Functional Directory	Yes	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
General 8	Responsibility/Organizational/Functional Codes	100%	94.38%	Fail	100.00%	Pass	100.00%	Pass	100.00%	Pass
General 9	Starting Tasks on Weekend or Holiday	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
General 10	Level of Effort Task	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
General 11	Critical Path Length Index (CPLI)	95%	108.15%	Pass	108.94%	Pass	112.22%	Pass	111.79%	Pass
Milestone 1	Ratio of Detail Tasks to Milestones	Low<=2, 10<=High	19.00	Fail	10.82	Fail	27.00	Fail	22.00	Fail
Milestone 2	Milestones Missing Predecessor or Successor	0%	25.00%	Fail	0.00%	Pass	0.00%	Pass	9.09%	Fail
Milestone 3	Milestones Missing Predecessor and Successor	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 4	Milestones Missing Predecessor	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	9.09%	Fail
Milestone 5	Milestones Missing Successor	0%	25.00%	Fail	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 6	Milestones with Resources	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 7	Milestones with Duration	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Milestone 8	Start and Finish Milestones	100%	100.00%	Pass	100.00%	Pass	100.00%	Pass	100.00%	Pass
Milestone 9	Tasks Marked both Milestone and Summary Task	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Duration 1	Dissimilar Time Units	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Duration 2	High Duration	5%	0.72%	Pass	1.63%	Pass	1.54%	Pass	4.27%	Pass
Duration 3	Extreme Duration	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Duration 4	Maximum Duration Limit (30 Days)	100%	80.58%	Fail	95.11%	Fail	96.92%	Fail	94.02%	Fail
Calendar 1	Working Calendars	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Calendar 2	Project Calendar	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Calendar 3	Holidays	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Logic 1	Basic Relationship (Open Ends)	0%	5.00%	Fail	0.00%	Pass	0.44%	Fail	1.97%	Fail
Logic 2	Missing Predecessor	5%	1.88%	Pass	0.00%	Pass	0.00%	Pass	1.97%	Pass
Logic 3	Missing Successor	5%	3.75%	Pass	0.00%	Pass	0.44%	Pass	0.79%	Pass
Logic 4	Relationship Type (Finish to Start)	90%	97.19%	Pass	88.39%	Fail	91.80%	Pass	92.75%	Pass
Logic 5	Circular Logics	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 6	Critical Path Test	YES	Yes	Pass	Yes	Pass	Yes	Pass	Yes	Pass
Logic 7	Percentage of Tasks on Critical Path	15~20%	1.25%	Fail	16.15%	Pass	11.11%	Fail	0.39%	Fail
Logic 8	Link in Summary Task	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 9	Link in Hammock	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Logic 10	Link in Level of Effort	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Constraint 1	Hard Constraints	0%	0.00%	Pass	0.38%	Fail	0.44%	Fail	3.54%	Fail
Constraint 2	No of Constraints	10%	3.13%	Pass	0.38%	Pass	0.44%	Pass	3.94%	Pass
Float 1	Total Float Contingency	10%	10.79%	Pass	7.45%	Fail	10.78%	Pass	11.34%	Pass
Float 2	High Total Float	5%	64.63%	Fail	25.39%	Fail	50.50%	Fail	60.41%	Fail
Float 3	Extreme Total Float	0%	23.81%	Fail	0.00%	Pass	0.50%	Fail	29.39%	Fail
Float 4	Negative Total Float	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Float 5	Maximum Total Float	0%	59.86%	Fail	10.88%	Fail	28.22%	Fail	36.73%	Fail
Lag 1	No. of Lags	5%	7.85%	Fail	11.80%	Fail	2.61%	Pass	3.13%	Pass
Lag 2	Lags with Resources	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass
Lag 3	Long Lags	5%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.75%	Pass
Lead 1	No. of Lead	0%	0.00%	Pass	0.00%	Pass	4.06%	Fail	9.90%	Fail
Lead 2	Leads with Resources	0%	0.00%	Pass	0.00%	Pass	0.00%	Pass	0.00%	Pass

Pass	37	**Pass**	40	**Pass**	40	**Pass**	37
Fail	12	**Fail**	9	**Fail**	9	**Fail**	12
Total	49	**Total**	49	**Total**	49	**Total**	49

Table 6. Results of OFPC Projects Evaluation by Metrics - 3

When a metric satisfies its threshold, it is labeled as “Pass”. Otherwise, it is labeled as “Fail”. The number of metrics that projects passed range from 33 to 45, where Project 5 passed the highest number (45) of metrics while Project 4 passed the lowest number (33) of metrics. In the following part, findings from the schedule quality evaluation results will be discussed in detail, starting from the metrics that all the projects failed to pass. It is worth noting that this evaluation process does not take into account OFPC's approvals for exceptions that the metrics regarded as fail. Instead, the evaluation was performed solely based on the data found in the schedules. Thus, the evaluation results can be slightly different from what OFPC approved and was aware of.

Analysis of OFPC Projects Evaluation Results

- Metrics that 13 OFPC projects failed to pass

1) Duration 4; Maximum Duration Limit (30 days)

It is recommended that the duration of detailed activities should not exceed 30 working days unless approved by the owner. If any, they should be broken down into more detailed activities for better management. It is identified, however, that all OFPC projects have detailed activities longer than 30 working days. The percentages of incomplete detailed activities whose durations are equal to or shorter than 30 work days range from 80.58% (112 out of 139 incomplete detailed activities in Project 10) to 98.38% (182 out of 185 incomplete detailed activities in Project 6) while the threshold for this metric is 100%. In Project 10, many kinds of activities for preparing/approving submittals as well as delivery have 40 work days, over the maximum duration limit. Other examples of activities exceeding the limit in the same project are "Install Electrical Raceways and Gear" (40 work days) and "Interior Finishes" (41 work days). In this case, dividing these activities, for instance, by locations, would optimize the tracking and reporting process. As for Project 6, the 3 incomplete detailed activities over the limit are "Fab/Del Pre Engineered Metal Building" (40 days), "Cure Foundation" (50 days), and "Cure Concrete" (50 days).

2) Float 2; High Total Float

High float metric helps to identify an unstable network or missing predecessors or successors. However, the check for high float is considered as controversial since there are many reasons that activities have a large amount of float (DCMA 2012). In the evaluation process, all the 13 projects failed to pass this metric. The main reason for this result is due to one of the OFPC's requirements; projects should have the minimum total float, at least 10% of the duration between "Notice to Proceed" to "Substantial Completion" (OFPC 2011). In other words, even though other organizations or agencies recommend having float equal to or less than 44 work days, the example projects tried to meet the OFPC's total float requirement properly. Considering this, rejecting a schedule only because it fails to pass this metric will be an unwise decision (DCMA 2012). Instead, contractual requirements should be carefully reviewed and satisfied.

- Metric that 12 OFPC projects failed to pass (Check in Primavera)

1) Float 5; Maximum Total Float

As stated above, OFPC articulates that no activity should have a total float amount greater the minimum total float identified by the Longest Path plus 45 work days (OFPC 2011). However, it is identified that all the projects except for Project 5 have total float greater than the maximum limit. The percentages of incomplete activities in the projects that failed to pass this check vary from 0.51% (1 out of 195 incomplete activities in Project 7) to 59.86% (88 out of 147 incomplete activities in Project 10). It is assumed that the longer the longest path is, the more activities that are not on the longest path have total float greater than the maximum limit.

- Metrics that 10 OFPC projects failed to pass

1) Milestone 1; Ratio of Detail Tasks to Milestones

This metric provides brief information on the level of planning detail of the schedule. The threshold for this metric is recommended to be between 2 to 10. It is found that 2 projects have a lower ratio value than 2 while 8 projects have a value greater than 10. It is assumed that the former 2 projects are not planned in detail enough or make milestones are less meaningful. On the other hand, the latter 8 projects seem that a number of activities need to be completed to achieve one milestone, which could mean that their schedules are highly detailed.

2) Logic 7; Percentage of Tasks on Critical Path

This metric helps check if a schedule is not overly serial and simplistic but practical. The recommended percentage of detailed activities on the critical path is between 15 to 20%. As mentioned above, in this research, tasks on the longest path were considered since a proportioned amount of total float was provided to each project as a cushion and management tracks the longest path. The evaluation results show that 5 projects have lower percentages while 5 projects have higher percentages than its threshold. The values of the calculated percentages range from 0.39% to 39.50%.

Interestingly, Project 10 and 13 have an extremely low value for this metric, 1.25% and 0.39%, respectively. The reason behind these values is a hard constraint, “Mandatory Finish”, on the “Final Completion” activity. Due to the hard constraint, only the “Final Completion” activity and its following activity, if any, end up having a longest path flag. Without the hard constraint on the “Final Completion” activity, the initial percentage values changed to 16.25% for Project 10 and 8.66% for Project 13. It is noteworthy that another hard constraint, “Finish On or Before”, affects the longest path flags differently. Since this hard constraint does not fix the finish date of a project as “Mandatory Finish” or “Finish On”, not only does it allow the change of the finish date, but also indicate activities on the longest path from the current status to the end of the project. For instance, when the “Mandatory Finish” constraint dated on January 14, 2010 on the “Final Completion” activity of Project 10 was switched to “Finish On or Before”, the early finish date of the activity changed from January 14, 2010 to December 7, 2009. Furthermore, 24 activities which previously were not highlighted as critical became on the longest path.

3) Lag 1; Number of Lags

It is known that lags help simplify a schedule by reducing the number of activities. At the same time, however, they do not provide detailed information on activities so that it is recommended that no more than 5% of the links that incomplete activities have with their predecessors have a lag. According to the evaluation results, 10 projects have more lags than the threshold and the percentage values are from 5.43% (19 lags in 365 logics of incomplete activities in Project 6) to 25.43% (104 lags in 409 logics of incomplete activities in Project 8). Additional attention on the lags would be required when managing a schedule having many lags.

- Metrics that 9 OFPC projects failed to pass

1) General 4; Task Name (Unique)

Unique task names help identify each task and minimize confusion between project participants. However, it is relatively common to find tasks using identical names even though they are executed at different times and in different locations. In this research, it is found that 9 out of 13 projects are using identical task names. Among them, Project 9 has the lowest value, 75.63%, which means that 90 out of 119 activities have unique activity names. However, it turns out that Project 9 uses different project IDs and activity IDs to differentiate those activities using the same names. In the case of Project 2, 84 out of 108 activities are using identical task names. Similarly, these activities are distinguished by different activity IDs. It seems that contractors assigned identical names but distinct project IDs or activity IDs to certain activities for identification. However, using unique task names in the first place appears to be more convenient and desirable.

2) Logic1; Basic Relationship (Open Ends)

It is ideal when every activity has at least one predecessor and successor except for the first and last activity. For instance, “Program Meetings” and “Kickoff Meeting” are commonly found as the first activity while “Substantial Completion”, “Final Completion”, and “Operational Occupancy” are occasionally identified as the last activity of the schedules. Another exception missing a logic relationship would be milestones simply for the informative purpose, such as “First Day of Fall Semester”. As for the evaluation values that failed to pass this metric, the minimum and maximum is 0.44% (Project 12) and 5.00% (Project 10), individually. In other words, in project 12, only 1 out of 225 activities is missing a successor relationship while in Project 10, 8 out of 160 activities are missing either a predecessor and/or successor. Interestingly, activities relative to meetings tend to miss a predecessor or successor. For instance, in Project 10, the activity “Joint Review for Owner Comments” was missing both a predecessor and successor and was constrained with a hard constraint, “Start On”.

3) Float 3; Extreme Total Float (Total Float greater than 120 working days)

It is found that 9 projects failed to pass this metric. The evaluation values of these projects range from 0.5% (1 out of 202 incomplete activities in Project 12 have extreme float) to 55.15% (434 out of 787 incomplete activities in Project 1 have extreme float). Extreme floats may indicate an unstable or logic-broken schedule so that they should be checked for the quality of a schedule. For instance, one activity both in Project 9 and 10 has an extreme total float, 176 and 152 days individually, because it missed a successor. However, it turns out that extreme total float is not always caused by an unstable or logic-broken schedule. In most cases, a long duration of the project and total float allowance in proportion to the duration of construction work lead to extreme total float. To be more specific, OFPC’s requirement that a schedule should have total float equal to or longer than 10% of the duration from “Notice to Proceed” to “Substantial Completion” increases the possibility of high float and extreme float. In short, the longer a project is, the more likely to have high and extreme float.

- Metric that 8 OFPC projects failed to pass

1) Logic 4; Relationship Type (Finish to Start)

Due to its explicit dependency description, it is recommended that at least 9 out of 10 logics use a Finish to Start (FS) relationship. However, the evaluation results indicate that in 8 OFPC projects, FS relationships account for less than 90% among the total logics. The lowest ratio value is 71.78% (1038 out of 1446 logics in Project 1) while the highest is 97.19% (242 out of 249 logics in Project 10). It is identified that Start to Start (SS) is the second most commonly used relationship type and Finish to Finish (FF) comes the next. With regards to Start to Finish (SF), only 3 projects used this relationship type and the number was less than 10.

- Metric that 7 OFPC projects failed to pass

1) Milestone 2; Milestones Missing Predecessor or Successor

This metric calculates the ratio of milestones missing a predecessor or successor to the total number of milestones in a schedule. It is recommended that every milestone has at least one predecessor and successor except for the start and finish milestone that begins and closes a project, respectively. For instance, a start milestone "Start Project" as well as a finish milestone "Final Completion" is exceptional. Also, informative milestones are considered as exceptional. One of the exceptions identified is "First Day of Fall Semester", which does not have a successor in Project 11. With regards to the 7

OFPC projects that failed to pass this metric, the evaluation values range 2.63% (1 out of 38 milestones in Project 2) from 25% (2 out of 8 milestones in Project 10).

- Metrics that 6 OFPC projects failed to pass

1) General 8; Responsibility/Organizational/Functional Codes

It is required to assign a responsibility code to activities for the purpose of indicating who is responsible for each activity (OFPC 2011). The evaluation results show that 6 projects did not assign a responsibility code to all the activities. The ratios of activities with a responsibility code to the total vary from 0.00% (0 out of 67 activities in Project 5) to 99.53% (210 out of 211 activities in Project 6). The only activity missing a responsible party in Project 6 turned out to be "Install Fence Fabric".

2) Constraint 1; Hard Constraints

The use of a late finish constraint on the schedule's last activity is allowed (OFPC 2011). In fact, a hard constraint "Mandatory Finish" is implemented on the activity, "Final Completion", in both Project 10 and 13. This exceptional use of a hard constraint is excluded from the metric calculation. It is found out that Project 13 has the highest ratio of hard constraints to the total activities (3.54%); in total, 10 hard constraints are used but 1 is exceptional as stated above. 9 hard constraints are either "Mandatory Start" or "Start On". The examples of activities having this hard constraint are associated with spring break, commencement, and meetings. The second highest ratio is 2.37% in Project 6. In this project, a hard constraint, "Start On" is frequently used, compared to other types of hard constraints. The examples of activities having a "Start On" constraint are "Owner

Authorizes Start of SD/DD”, “Owner Receives Request for Qualifications”, “Owner Issues Request For Proposals”, and “Owner Receives Request for Proposals”. The difference between “Start On” or “Finish On” and “Mandatory Start” or “Mandatory Finish” hard constraints is that “Start On” and “Finish On” constraints will protect the network logic and only cause a negative float in the network when an activity with either of them is delayed. On the contrary, “Mandatory Start” and “Mandatory Finish” constraints remove the negative float and move the activity in violation of their calculated dates.

3) Lead 1; Number of Lead

The evaluation results show that 6 OFPC projects have leads in the logics between incomplete activities and their predecessors. The metric calculation values of these 6 projects range from 1.28% (1 out of 78 incomplete activities has a lead in Project 2) to 9.90% (38 out of 384 incomplete activities have a lead in Project 13). Since it is challenging to demonstrate negative time and leads may distort total float, it is recommended to replace a lead by a positive lag on a Start to Start (SS) relationship or a couple of smaller-duration activities with Finish to Start (FS) relationships having no lags.

- Metric that 4 OFPC projects failed to pass

1) Milestone 5; Milestones Missing Successor

The evaluation results show that 4 OFPC projects have milestones missing a successor. It is recommended that all the milestones have at least one successor whereas a finish milestone that closes a project is regarded as exceptional. Such exceptional finish milestones were found in the schedules and were excluded during the evaluation. “Operational Occupancy” and “Final Completion” are the examples. On the other hand, the examples of milestones missing a successor are “Systems Commissioning” and “Geotechnical Report”, among others.

- Metrics that 3 OFPC projects failed to pass

1) Milestone 4; Milestones Missing Predecessor

It is desirable that all the milestones have at least one predecessor. However, the evaluation summary indicates that 3 projects failed to pass this check. When a start milestone that begins a project is missing a predecessor, it is regarded as an exception. This kind of exception was considered when the metric evaluated the 13 schedules. The examples of such exceptional milestones found are “Start Project”, “Owner Authorizes Start of SD/DD”, and “Kickoff Meeting”. On the contrary, the activity “Building Dry-In” and “Owner Receives Request for Qualifications” are the examples of milestones missing a predecessor.

2) Float 1; Total Float Contingency

It is required for a schedule to include total float equal to or more than 10% of the duration from the effective date of Notice to Proceed (NTP) for construction services to the substantial completion date (OFPC 2011). However, 3 OFPC projects failed to pass this float contingency metric. The metric calculation values of these 3 projects are 9.23% (43 TF/466 duration of Project 2), 1.64% (5 TF/304 duration of Project 4), and 7.45% (21 TF/282 duration of Project 11). Project 2, 4, and 11 should have had more than approximately 47, 31, and 29 days individually as a total float contingency to meet the requirement.

- Metric that 2 OFPC project failed to pass

1) Duration 2; High Duration

Every project except for Project 2 and 8 passed this metric. This means that in Project 2 and 8, 8.70% (4 out of 46) and 6.19% (12 out of 194) of incomplete detailed activities have duration longer than 44 working days, respectively. Other 11 projects also have high duration activities but the percentages of incomplete detailed activities with high duration were lower than the threshold, 5%.

- Metrics that 1 OFPC project failed to pass

1) General 10; Level of Effort Task

As activities that cannot be associated with a physical product, do not represent discrete effort, and only last until detailed activities that they support are completed, it is recommended that LOE activities are not on the critical path (GAO 2012). In the 13 OFPC projects, only one LOE activity was found but it was on the longest path. It turns out that this LOE activity has a successor activity and this successor caused it to be on the longest path. When this successor logic was removed, the LOE activity was off the longest path.

2) Duration 3; Extreme Duration

It is found out that Project 2 has one activity that has an extremely long duration, longer 125 working days, among 46 incomplete detailed activities. This activity is “Pk 5 – Construction” and its duration is 230 working days. It is assumed that this part of the schedule was not developed in detail at the time of baseline schedule submission.

3) Logic 10; Link in Level of Effort

It is known that LOE activities do not represent discrete effort but simply support detailed activities, which is why their duration is determined by the overall duration of the discrete work they support. Therefore, it is desirable when LOE activities do not drive any successor and become critical (GAO 2012). Otherwise, LOE activities will have an impact on the logic and total duration of a project. However, in Project 4, one activity linked to a LOE activity, “Stage 2 - Additional Floor Finish out”, as a successor was identified and it caused the LOE activity to be on the longest path.

4) Constraint 2; Number of Constraints

The evaluation results show that only Project 4 used constraints on more than 10% of the total activities (constraints on 12 out of 107 activities) while other 7 projects used constraints but less than the threshold (10%). The use of a late finish constraint on the schedule’s last activity is regarded as exceptional as OFPC allows this point (OFPC

2011). In the Project 4, one hard constraint, “Finish On or Before” was used on the activity “Change Order Signed”. The rest was soft constraints, such as “Start No Earlier Than” and “As Late As Possible”.

- Metrics that all OFPC projects passed

1) General 1; Project ID

It is found that every OFPC project has its own unique project ID to distinguish one from others. OFPC has a numbering system using 6 digit numbers to assign a project a unique project ID.

2) General 2; Project Name

The evaluation results show that every OFPC project has a unique project name, which helps distinguish one from other projects. Generally speaking, OFPC uses the name of a building as a project name for convenient identification and communication.

3) General 3; Task ID

This metric identifies if all the activities in the schedule have a unique task ID. It turns out that every task ID in the schedules of OFPC projects is distinct from others.

4) General 5; Task Name (Descriptive Name)

It is recommended that all the tasks in the schedule have a name that describes what is to be done. According to the evaluation results, all the 13 OFPC projects passed this check.

5) General 6; WBS Element ID/Reference

It is required to assign a WBS ID to each task for convenient and efficient tracking process. The evaluation results show that all the projects passed this check. This metric checks if each activity has a WBS ID assigned but not if each activity has a unique WBS ID since depending on the level of detail, identical WBS ID can be utilized

6) General 7; Responsibility/Organizational/Functional Directory

This metric checks if a responsibility/organization/functional directory exists for the assignment of responsibility codes to every project participant. The evaluation results indicate that all the schedules for OFPC projects have a responsibility/organizational/functional directory.

7) General 9; Starting Tasks on Weekend or Holiday

It is ideal and realistic if a task starts on a work day. This check is to figure out if there is any task that starts on the weekends or a holiday. It is found out that all the OFPC projects passed this metric.

8) General 11; Critical Path Length Index (CPLI)

CPLI is known as an indicator of the efficiency or achievability of a project on time. In this research, a ratio of the project longest path plus the project total float to the project longest path was computed for this metric evaluation. Thanks to the total float allowance requirement of OFPC projects, every project satisfies the CPLI threshold, 0.95 or 95%. In fact, the CPLI value of every project is greater than 100%, which means that there is positive total float on the longest path. The minimum CPLI value is 101.55% while the maximum is 130.85%.

9) Milestone 3; Milestones Missing Predecessor and Successor

It is recommended that every milestone has at least one predecessor and one successor unless it is the first and last activity in the schedule. As for the result of this metric, every OFPC project satisfies the threshold; no milestone missing both a predecessor and successor is identified.

10) Milestone 6; Milestones with Resources

It is ideal that milestones have no resources and duration. The evaluation results also indicate the same thing that all the OFPC projects did not assign any resources as well as duration to milestones.

11) Milestone 7; Milestones with Duration

As stated above, it is desirable that every milestone has neither duration nor resources and, in fact, no milestone in the schedules turns out to have duration and resources.

12) Milestone 8; Start and Finish Milestones having a start and finish date.

It is recommended that all the start milestones have a specific start date while all the finish milestones have a certain finish date assigned. The results show that every start and finish milestone has a start and finish date, respectively.

13) Milestone 9; Tasks Marked both as a Milestone and Summary Task

An Activity should not be both a summary and a milestone. They are distinct from each other in terms of their purpose, duration, and logic relationship. No project has a task marked both as a milestone and summary task.

14) Duration 1; Dissimilar Time Units

It is desirable that all the activities in the schedule use the same time unit. It is identified that all the OFPC projects passes this metric.

15) Calendar 1; Working Calendars

It is important that a calendar indicates work period with a proper time unit, such as days or hours. It turns out that every project uses an adequate calendar that represents durations in days.

16) Calendar 2; Project Calendar

It is common to create a customized project calendar for a specific project. In that case, it should be assured that such calendar is utilized for the right project. It is identified that some projects used a calendar customized by a contractor while some utilized a standard calendar. With regards to the evaluation results, all the projects passed this metric.

17) Calendar 3; Holidays

It is imperative to take into account holidays for a realistic schedule. The evaluation results show that every project utilized a calendar that considers holidays.

18) Logic 2; Missing Predecessor

Generally speaking, every activity should have at least one predecessor unless it is the first activity in the schedule. The values of this metric evaluation results range from 0.00% to 3.74% while its threshold is 5%. It is identified that activities for meetings, for instance, tend to miss predecessor logic since they are scheduled on a specific date.

19) Logic 3; Missing Successor

Generally speaking, every activity should have at least one successor unless it is the last activity in the schedule. Another exemption would be Level of Effort activities since they are required not to have a successor so that their durations are dependent on the activities that they support. The values of this metric evaluation results range from 0.00% to 3.75% while its threshold is 5%. The examples of activities missing a successor are activities for meetings or review owner's comments.

20) Logic 5; Circular Logics

It is recommended that every schedule does not have a circular logic. In fact, Primavera has a function that gives a warning sign when a circular logic is identified. Regarding the evaluation result, no project failed to pass this metric.

21) Logic 6; Critical Path Test

Critical Path Test helps to figure out if there is any broken logic in a schedule. Every project showed that when an intentional slip was applied to activities on the longest path, its total float was consumed first, if any, and its duration was delayed in proportion to the amount of the slip. To be clear, the schedule is delayed only when the slip was bigger than its total float. It is identified that Project 8, 10, and 13 assigned a hard constraint, such as “Finish On” or “Mandatory Finish”, on their last activities, which caused only them to be critical activities. Thus, such hard constraints were removed first to figure out the chain of activities that determines each project’s completion date, and then the test was performed. It turns out that every project satisfies this evaluation.

22) Logic 8; Link in Summary Task

Predecessor or successor links with summary tasks are avoided since the start and finish dates of summary tasks should be dependent on lower-level detailed activities rather than their logic relationships. Ideally, no link in a summary task is found among the 13 OFPC projects.

23) Logic 9; Link in Hammock

Similar to summary tasks, hammocks should not have logic relationships. The evaluation results show that every project passed this metric.

24) Float 4; Negative Total Float

Generally speaking, it is ideal not to have a negative float in a schedule. Negative total float represents the amount of time that must be recovered so as not to delay a project’s finish date beyond its constrained date (GAO 2012). Even though the activity “Final Completion” of Project 10 and Project 13 is constrained with “Mandatory Finish”, no negative float is found in the schedules since they are the baseline schedules which actual progress is barely recorded in and have generous total float.

25) Lag 2; Lags with Resources

It is known that lags indicate the passage of time with no effort or resources. As such, lags should not have resources. The evaluation results show the same point; no schedule has a lag with resources information.

26) Lag 3; Long Lags (30 working days)

The use of lags helps reduce the number of activities and streamline a schedule. However, it is recommended that lags should not be longer than 30 working days since they rarely provide detailed information and contain risks. It is identified that 7 projects have lags longer than 30 working days but all the 13 projects satisfied this test. The percentage values of long lags in these 7 projects vary from 0.07% (1 out of 1446 links in Project 1) to 3.36% (15 out of 446 links in Project 8). The longest lag found in the 7 project having long lags ranges from 40 to 140 working days.

27) Lead 2; Leads with Resources

Similar to lags, leads should not have resources. Fortunately, the evaluation results show that no schedule has a lag and lead with resources information.

Chapter 6: Conclusions

This research has collected and organized 49 schedule quality metrics and their thresholds from a wide array of professional organizations and government agencies in an effort to contribute to the process of assessing and improving the quality of baseline schedules. The 49 metrics are divided into 9 categories; General, Milestone, Duration, Calendar, Logic, Constraint, Float, Lag, and Lead. The number of metrics in categories differs from 2 to 11. When comparing each category, the number of metrics regarding general project and activity information, milestone, and logic is relatively higher than that of other categories.

The schedule evaluation results show that the number of tests passed range from 33 to 45 among the total 49 tests. It is identified that among the 49 metrics, at least one project failed to pass 22 metrics while all the projects passed the other 27 metrics. To be more specific, the majority of projects, 7 out of 13 projects, missed 11 tests. These tests are as follows; [Duration 4] maximum duration limit (30 work days), [Float 2] high total float (44 work days), [Float 5] maximum total float (float on the longest path + 45 work days), [Milestone 1] ratio of detail tasks to milestones, [Logic 7] percentage of tasks on critical path, [Lag 1] number of lags, [General 4] unique task names, [Logic 1] open ends, [Float 3] extreme total float (120 working days), [Logic 4] relationship type, and [Milestone 2] milestones missing a predecessor or successor. It is worth noting that this evaluation process does not take into account OFPC's approvals for the exceptions, if any, which the metrics regarded as fail. Instead, the evaluation was performed solely based on the data found in the schedules. Thus, the evaluation results can be slightly different from what OFPC approved and was aware of.

Interestingly, all projects failed to pass the maximum duration limit and high float test. The former test is one of the OFPC‘s requirements but it turns out that 1.6% to 19.42% of detailed activities in 13 projects have a duration longer than 30 workdays. The second test appears to be controversial since guidelines or best practices from other organizations or agencies are in conflict with what OFPC requires from a contractor; 44 working days is the commonly recommended float limit while OFPC requires 10% of the project duration as float. In the same context, extreme float test which recommends that float be less than 120 working days must have been affected by its requirement. This shows that the metrics and/or thresholds proposed by professional organizations should not be considered as unquestionable. It is wise that each entity develops its own database from past projects and modifies them to suit their specific conditions and needs. However, it is interesting to see that 12 projects have bigger float than OFPC’s maximum float, which is 45 working days plus total float on the longest path.

When new facility and renovation projects were compared, no substantial discrepancy was identified; the average number of metrics satisfied for the new facility projects is 38.4 while that of renovation projects is 37.3. The standard deviation of the former group is 4.2 whereas that of the latter group is 2.1. There is a relatively noticeable difference in the ratio of detail tasks to milestones; when 3 out of 7 new facility projects passed this test, 0 renovation projects satisfied this test.

As a variety of guidelines and best practices from many professional organizations and government agencies intended, quantitative baseline schedule quality metrics and thresholds will facilitate the schedule assessment process. Moreover, they will assist in identifying component-related and/or contractual problems in schedules and improving schedule quality for successful projects. If the suggested metrics and thresholds are reviewed, updated, and customized by a potential user based on their database and specific conditions and needs, evaluation results will become more realistic, meaningful, and accurate.

Chapter 7: Recommendations

For recommendations, an emphasis is placed on the 11 tests that the majority of previous OFPC projects failed to pass for future projects. Among them, however, metrics for checking high total float, Float 2, and extreme total float, Float 3, will not be discussed in this chapter since the maximum total float test, Float 5, is more applicable to OFPC projects. The tests chosen for recommendations are listed as follows;

- [General 4] Task Names (Unique) [9/13]
- [Milestone 1] Ratio of Detail Tasks to Milestones [10/13]
- [Milestone 2] Milestones Missing a Predecessor or Successor [7/13]
- [Duration 4] Maximum Duration Limit (30 Work Days) [13/13]
- [Logic 1] Basic Relationship (Open Ends) [9/13]
- [Logic 4] Relationship Type (Finish to Start) [8/13]
- [Logic 7] Percentage of Tasks on Critical Path [10/13]
- [Float 5] Maximum Total Float (Float on Longest Path + 45 Work Days) [12/13]
- [Lag 1] Number of Lags [10/13]

Other tests regarded as crucial for reviewing schedules are the followings;

- [Constraint 1] Hard Constraints [6/13]
- [Float 1] Total Float Contingency [3/13]
- [Lead 1] Number of Lead [6/13]

The values on the right side represents the number of projects that failed to pass each metric. For instance, in the case of Constraint 1, 6 projects failed to pass this test while 7 projects satisfied its threshold. Recommendations based on the evaluation results of these metrics will be provided below in order of the metrics categories.

When it comes to task names, it would be ideal to have unique names starting with a verb to indicate what is to be done and end with a location so that they are distinct from others. Different activity IDs help differentiate tasks with an identical name but unique names will make it easier to distinguish them. Considering that duplicate task names were found in most projects, more attention on assigning unique names with more information, such as location, will be needed in future projects.

As an indicator of the level of planning detail, the ratio of detail tasks to milestones was suggested by the United States Government Accountability Office (GAO). It did not provide a specific proven threshold but suggested a rough value to check if a schedule has detail tasks enough to achieve milestones. Among the 10 projects that did not pass this test, 8 projects have a ratio value bigger than 10 while the rest have a value smaller than 2. It appears that projects having too many detail tasks or too few milestones are more common than those having too few detail tasks or too many milestones. In other words, it is more likely to see a schedule that requires many tasks to be completed to achieve one milestone. This point should be taken into account when OFPC reviews schedules in the future. Having an adequate ratio of detail tasks to milestones would help monitor work progress.

With regards to logics, both milestones and detailed activities missing a predecessor and/or successor should be avoided to secure the correct sequence of work and calculate the accurate total duration of a project. Since projects having detailed activities and milestones missing logics were commonly identified, more attention on open ends is necessary in future projects. When open ends are identified excluding exceptions, such as the first and last activity of a schedule or an activity for information, it is imperative to see if the missing logics can be defended.

As OFPC specifications for project planning and scheduling indicate, it is imperative to have well-defined activities whose durations are shorter than 30 work days for better tracking and management. In every case project, activities longer than 30 work days were often found. This shows the necessity of reviewing the durations of activities and having more manageable detailed activities. When activities longer than 30 work days are identified, it would be better to break them down into more detailed activities unless approved by OFPC.

Among logic relationship types, a Finish to Start (FS) relationship is regarded as the most straightforward logical link. This relationship indicates that an activity cannot start until its predecessor activity is completed. Start to Start (SS) and Finish to Finish (FF) relationships are also necessary to represent a schedule with efficiency and accuracy. On the contrary, a Start to Finish (SF) relationship is rarely used and sometimes even discouraged since it directs a successor activity not to finish until its preceding activity starts, which reverses the work sequence (GAO 2012). In other words, it tends to overcomplicate the schedule network logic. In this context, checking relationship types used will contribute to developing a straightforward and intuitive schedule. It is, however, worth noting that rejecting a schedule solely based on the fact that less than 90% of logics are FS relationships would be an unwise decision (DCMA 2012).

A test to check the percentage of tasks on the critical or longest path can help measure the level of planning detail of a schedule. The evaluation result shows that half of the 10 projects that failed to pass this test have too few activities on the longest path while the rest have too many activities on it. The former would indicate that it is overly simplified while the latter would mean the opposite. Provided that both overly simplified and detailed schedules make it challenging to monitor the work progress, it would be crucial to have the adequate number of activities on the critical or longest path. This test will contribute to checking the planning detail level and performing a monitoring task later. One thing to keep in mind is that the existence of a hard constraint such as "Mandatory Finish" or "Finish on" affects the test result substantially so that removing it temporarily, if any, would be necessary to perform the test correctly.

With regards to hard constraints, OFPC specifies that a schedule shall be free of any mandatory constraints but late finish constraints can be applied to the last activity in a schedule. A hard constraint can be utilized to calculate available total float up to a key milestone. It is also known that the temporary use of a hard constraint helps assess the likelihood that using available resources can achieve a planned activity date. However, a hard constraint such as "Mandatory Finish" or "Finish On" fixes the finish date of an activity so that it becomes critical immediately, which convolutes critical path calculations and reduces the credibility of any schedule date of activities after the constrained one (GAO 2012). To avoid any unintended change on the dates of activities and calculation of the critical or longest path, it is imperative to identify hard constraints and validate their uses in the future projects.

As one of the OFPC requirements, 10 out of 13 projects successfully passed the total float contingency test; even two of the three projects that did not pass had a float contingency value very close to its threshold. This finding shows the commitment of a contractor to meeting this requirement and that of OFPC to reviewing their schedules. It would be ideal if every project in the future satisfies this requirement unless they are allowed as an exception. For this, continuous review and evaluation efforts would be required. In addition, commonly found are activities having total float greater than the minimum total float identified by the longest path plus 45 days. Since a missing or incorrect logic can cause a huge amount of total float and misrepresent the flexibility of a schedule, it is recommended to check activities having a relatively excessive amount of total float.

It was identified that OFPC Project Planning and Scheduling specifications do not address the use of lags. Generally speaking, a lag in logic between two activities indicates the passage of time with which no effort or resources are associated. Lags are useful when a part of long-term efforts in a summary or intermediate schedule is likely to be unknown or when the number of activities needs to be reduced. If used improperly, however, lags can distort float calculations and harm critical path calculations in a schedule (GAO 2012). This problem can occur when lags make non-critical activities critical by consuming total float or extending the finish date of the schedule. The danger in using lags is that they are not readily noticed and not considered as drivers of the finish milestone date. In addition, lags and leads are static so that updating them is time-consuming and prone to error if they are widely used (GAO 2012). For these reasons, lags should be monitored and reviewed to check whether they are utilized in a practical and proper manner. Considering that 10 out of 13 projects had lags more than the recommended threshold, it is likely to see projects using many lags. Checking the use of lags will help reduce unnecessary lags. Even if this metric is satisfied, monitoring lags would be needed to avoid the miscalculation of float and the critical path.

As negative lags, leads imply negative time and are used to accelerate a successor activity. Similar to lags, leads can cause several problems including challenging identification of leads, distorted calculation of total float or the critical path, and time-consuming and error-prone updating process. Besides, leads require accurate foresight about future events to determine their time amount. A logic failure can also occur when a lead is longer than a successor activity, which results in a predecessor activity planned to finish later than its successor. For these reasons, it is recommended to avoid using leads. It is known that a lead can be replaced by a positive lag on a Start to Start (SS) relationship or a couple of smaller-duration activities with Finish to Start (FS) relationships having no lags. Replacing leads would help develop a more straightforward, detailed, and accurate schedule. It would be wise to check the use of leads in future projects and, if any, they should be reviewed and monitored to prevent the abovementioned problems.

Lastly, this thesis is mainly focusing on the components of schedules even though the development process of schedules is also imperative to develop a quality schedule (Moosavi and Moselhi 2012). For instance, a criterion regarding "Subcontractors Participation" was recommended in various references to develop a realistic and practical schedule in which procedures and opinions of construction work performers are embedded (De La Garza 1988; Zack Jr. 1993). Without a doubt, it is imperative to check not only whether a schedule includes a defined project scope properly, but also whether subcontractors participate in the schedule development process, if procured, during workshops (Moosavi and Moselhi 2012). In fact, OFPC requires planning and scheduling workshops prior to submitting a construction schedule to the owner for verifying schedule submittals. Likewise, OFPC should focus on both the components and development process of schedules for future projects.

References

Associate for the Advancement of Cost Engineering International (AACEI) (2014). “Cost Engineering Terminology”. Available at: <www.aacei.org>. Last access: April 23, 2015.

Associate for the Advancement of Cost Engineering International (AACEI) (2013). “AACE International’s Certified Scheduling Technician (CST) Primer”. Available at: <http://www.aacei.org/cert/CST/CST_Primer.pdf>. Last access: April 23, 2015.

Business Dictionary.com (2015). Available at: <http://www.businessdictionary.com/definition/threshold.html>. Last access: April 23, 2015.

Center for Earned Value Management (CEVM) (2008). “Analysis Toolkit”. Available at: <http://www.secnav.navy.mil/rda/OneSource/Documents/CEVM/Tools%20and%20Examples/Navy%20Guides/cevmanalysistoolkitfinal20080813.pdf>. Last access: April 23, 2015.

De La Garza, J. (1988). “A knowledge engineering approach to the analysis and evaluation of schedules for mid-rise construction”. PhD Thesis. University Of Illinois At Urbana-Champaign, Urbana, IL.

Defense Acquisition University (DAU) (2011). “Better Schedule Performance Assessments Derived From Integrated Master Plan-Referenced Schedule Metrics”. Available at <http://www.dau.mil/pubscats/pubscats/ar%20journal/arj60/bachman_arj60.pdf>. Last access: April 23, 2015.

Department of Defense (DOD) (2012). "Over Target Baseline and Over Target Schedule Guide". Available at: <http://www.acq.osd.mil/evm/docs/OTB-OTS%20Guide%20121205.pdf >. Last access: April 23, 2015.

Department of Defense (DOD) (2005). "Integrated Master Plan and Integrated Master Schedule Preparation and Use Guide". Available at <http://www.acq.osd.mil/se/docs/IMP_IMS_Guide_v9.pdf>. Last access: April 23, 2015.

Li, W. G., and Carter, D. J. (2005). "Construction Baseline Schedule Review and Submittal Timeframe". In: Cost Engineering, 47(2), p. 28-36.

Moosavi, F., and Moselhi, O. (2014). "Review of Detailed Schedules in Building Construction." In: Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 6(3), 05014001.

Moosavi, S. and Moselhi, O. (2012). "Schedule Assessment and Evaluation". In: Proceedings of Construction Research Congress 2012, p. 535-544.

National Aeronautics and Space Administration (NASA) (2010). "NASA Schedule Management Handbook". Available at <http://www.nasa.gov/pdf/420297main_NASA-SP-2010-3403.pdf>. Last access: April 23, 2015.

National Defense Industrial Association (NDIA) (2012). "Planning and Scheduling Excellence Guide". Available at: <http://www.efcog.org/wg/pm_evmssg/docs/NDIA_PASEG.pdf>. Last access: April 23, 2015.

Naval Air (NAVAIR) (2010). "Integrated Master Schedule (IMS) Guidebook". Available at: <https://acc.dau.mil/CommunityBrowser.aspx?id=526558>. Last access: April 23, 2015.

Office of Facilities Planning and Construction (OFPC) (2015). “About OFPC”. Available at: <https://www.utsystem.edu/fpc/about_index.html>. Last access: April 23, 2015.

Office of Facilities Planning and Construction (OFPC) (2011). “Section 01 32 00 Project Planning and Scheduling”. Last access: April 23, 2015.

Project Management Institute (PMI) (2007). “Project Standard for Scheduling”. Available at: <http://www.rdbc-international.org/uploads/soft/121022/1-121022213647.pdf>. Last access: April 23, 2015.

Spillinger, R. (2000). “Adding Value to the Facility Acquisition Process: Best Practices for Reviewing Facility Designs”. Washington, D.C.: NATIONAL ACADEMY PRESS. 21 pp.

United States Government Accountability Office (GAO) (2012). “Schedule Assessment Guide”. Available at: <http://www.gao.gov/assets/600/591240.pdf>. Last access: April 23, 2015.

Winter, R. (2011). “DCMA 14-Point Schedule Assessment”. First Annual Construction CPM Conference, Orlando, FL.

Zack, J., Jr. (1993). “Closure to “Schedule ‘Games’ People Play, and Some Suggested ‘Remedies’” by James G. Zack Jr. (April, 1992, Vol. 8, No. 2)”. In: Journal of Management in Engineering, 9(3), p. 285-286.

Zafar, Q. Z., and Rasmussen, D. (2001). “Baseline Schedule Approval”. In: Cost Engineering, 43(8), p. 41-43.